PROCEEDINGS

-Twenty-Eighth-
U.S. Army Operations Research Symposium

AORS XXVIII

10-12 October 1989
Fort Lee, Virginia

OPERATIONAL TEST AND EVALUATION AGENCY
UNITED STATES ARMY

VOLUME I

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19. ABSTRACT (Continue on reverse if necessary and identify by block number)

This document is a collection of technical papers and speeches presented to the Twenty-eighth annual Army Operations Research Symposium (AORS XXVIII). The purpose of each AORS is to foster communication, exchange information, and recognize high quality work within the Army analytical community. The theme of this year's symposium was "Maximizing Army Effectiveness." General subject areas were: A. Readiness, Sustainability & Support to Forces in the Field; B. Testing, Field Experiments & Training; C. Command, Control, Communications, Computers, Intelligence on the Battlefield; D. System Effectiveness and Survivability on the Realistic Battlefield; E. Recent Advances in OR Methodology, Evaluation Techniques and Other Selected Topics; F. Force Design Planning, Programming & Modernization; G. Manpower and Personnel Analyses; H. Joint Forces and Strategic Operations; I. Cost Estimating and Analysis; J. Military Engineering. The PROCEEDINGS are printed in two volumes; Volume I contains all papers with unlimited distribution, and abstracts of others; Volume II contains papers with distribution limited to DoD components only. Keywords.

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FOREWARD

The United States Army Operational Test and Evaluation Agency (USAOTEA), Alexandria, Virginia was honored to sponsor the Twenty-Eighth annual U.S. Army Operations Research Symposium (AORS XXVIII) at Fort Lee, Virginia, 10-12 October 1989.

The AORS XXVIII theme, "Maximizing Army Effectiveness", was selected to focus on analytical methods and products that enhance Army analysis and expose the practitioners to constructive critique and, in general, broaden the perspective of the Army analysis community. Over 320 analysts from U.S. government, U.S. industry, academia, and four foreign countries participated in the symposium. There were 126 presentations given in the General Sessions, 10 Special Sessions and 2 additional special session presentations. The DA Systems Analysis Awards for exceptional work by an individual and a group were presented.

This was the sixteenth consecutive year that the AORS was held at Fort Lee. As always, the U.S. Army Logistics Management College and the U.S. Army Logistics Center and Fort Lee provided outstanding support. The General Session speakers, Special Session Chairmen, Special Session speakers, symposium planners, and workers also deserve credit for the success of the symposium. USAOTEA gratefully acknowledges the outstanding efforts of all involved in AORS XXVIII.

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Symposium Coordinator
LTC Neal R. Jensen

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PREFACE

The proceedings of AORS XXVIII are unclassified and divided into two volumes. The volumes are divided into three parts: the agenda, the DA Systems Analysis Awards Presentation, and the prepared papers. Volume I contains all papers authorized for unlimited distribution and abstracts for all other papers. Volume II contains those paper which were authorized for distribution to DoD components only. No classified papers were prepared for release.

Individuals interested in obtaining material presented at the symposium but not published in the proceedings should contact the author(s) directly.

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PART I. AGENDA

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10 October 1989

1800-2000	REGISTRATION AND SOCIAL Main Ballroom--Fort Lee Officer's Club

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0730-0815	AORS Shuttle Busses Depart Government Quarters and AORS Parking Lot for Bunker Hall.
0800-0830	MAKE-UP REGISTRATION Control Room B200, Bunker Hall
0830-1130	SESSION I--OPENING GENERAL SESSION Green Auditorium, Bunker Hall
0830-0855	WELCOME AND ADMINISTRATIVE ANNOUNCEMENTS
0855-0955	KEYNOTE ADDRESS
0955-1015	BREAK
1015-1115	ADDRESS MG Willaim H. Reno Headquarters, Department of the Army
1115-1130	INTRODUCTION OF SPECIAL SESSION CHAIRMEN Dr. Henry C. Dubin Technical Director, U.S. Army Operational Test and Evaluation Agency
1130-1300	LUNCH
1300-1700	SESSION II--NINE CONCURRENT SPECIAL SESSIONS Bunker Hall Classrooms
1705-1725	AORS Shuttle Busses Depart Bunker Hall for AORS Parking Lot and Government Quarters
1700-1800	SESSION III--ADDITIONAL SPECIAL SESSION Classified Special Session Blue Auditorium, Bunker Hall

	Special Cost Analysis Presentation Room B136, Bunker Hall
1805-1825	AORS Shuttle Busses Depart Bunker Hall for AORS Parking Lot and Government Quarters
1830-1930	SOCIAL HOUR Fort Lee Officer's Club
1930	BANQUET Main Ballroom, Fort Lee Officer's Club Guest Speaker: Honorable Denny Smith Representative-Oregon, U.S. Congress

12 October 1989

0715-0745	AORS Shuttle Busses Depart Government Quarters and AORS Parking Lot for Bunker Hall
0800-1200	SESSION IV--TEN CONCURRENT SPECIAL SESSIONS Bunker Hall Classrooms
1200-1300	LUNCH
1300-1510	SESSION V--CLOSING GENERAL SESSION Green Auditorium, Bunker Hall
1330-1430	PRESENTATION Armor/Antiarmor System Mix Analysis TRADOC Analysis Command RAND-Arroyo Center
1430-1440	FA 49 UPDATE BG Robert T. Howard U.S. Army Personnel Command
1440-1450	ORSA 1515 UPDATE Mr. Michael Sandusky Headquarters, U.S. Army Materiel Command
1450-1510	PRESENTATION OF DA SYSTEMS ANALYSIS AWARD Mr. Walter W. Hollis Deputy Under Secretary of the Army (Operations Research)
1510	ADJOURNMENT
1515-1545	AORS Shuttle Busses Depart Bunker Hall for AORS Parking Lot and Government Quarters

PART II. DA SYSTEMS ANALYSIS AWARDS

DA SYSTEMS ANALYSIS AWARD PRESENTATION
AT THE
TWENTY-EIGHTH U.S. ARMY OPERATIONS RESEARCH SYMPOSIUM
12 OCTOBER 1989

PRESENTER:
MR. WALTER W. HOLLIS
Deputy Under Secretary of the Army for Operations Research

INDIVIDUAL AWARD WINNER:
MAJ Mark A Youngren
U.S. Army Concepts Analysis Agency
for his work on
"Updating Nuclear Effects in Theater Models"
(and other works)

GROUP AWARD WINNER:
LTC Michael V. Farrell
MAJ Stephen G. Baldwin
MAJ David W. Cammons
Mrs. Susan D. Solick
Mr. Michael S. Cox
Mr. John C. Abshier
Mrs. Cindy L. Sullivan
Mr. Arley C. Cordonier
U.S. Army TRADOC Analysis Command
for their work on
"Armor/Antiarmor Master Plan Supporting Analysis"

PART III. SPECIAL SESSION PAPERS

UNIT STATUS REPORTING

LTC Gilbert S. Harper
Logistics Directorate, J-4
The Joint Staff

Completing a unit status report using AR 220-1 is a frustrating experience. Its complexity requires a major effort by unit level personnel and supporting agencies. It is even more difficult to derive from the report a true picture of a unit's ability to accomplish a specific mission. Instead the report identifies specific shortages of equipment and personnel or training and maintenance shortfalls to justify the overall readiness rating of each category. It does nothing to link those shortfalls to accomplishment of mission essential tasks. The present system is adequate but its potential for improvement is small.

The unit readiness reporting system, as any information management system, should provide the commander or other decision maker with the information needed to make a decision. To accomplish this general goal the system should

* consolidate all relevant information,
* analyze that information,
* tailor it to the specific needs of each commander involved,
* and provide it to the decision maker in an efficient form.

All extraneous information should be removed so that the commander gets all the information he needs but only the information he needs. I believe the present system floods the commander not with analysis but with details, some relevant, some not. We need a new system that will accurately assess and communicate mission readiness in a manner that will facilitate evaluation of a unit's ability to accomplish a specific plan and identify specific problems impacting on mission capability. This article offers a conceptual system to accomplish these goals.

ELEMENTS OF READINESS

To accomplish the mission the commander needs trained and equipped personnel at the point of decision. Hence we have thekey elements of unit readiness:

Personnel
Training
Equipment on Hand
Equipment Readiness
Deployability
Sustainability

The present system considers the first four elements but not the last two. Hence, it omits some of the information that may be essential to making command decisions on mobilizing and deploying the force.

There is a more serious problem with the present system in that it can report a rating higher than the unit's actual capability. Consider a fictitious unit, which for simplicity consists of four different military occupational specialties (MOS1, MOS2, MOS3, MOS4) and four corresponding pieces of essential equipment (E1, E2, E3, E4).[1] Assume authorizations and availabilities are as shown in table 1.

	Authorized	On-Hand	C-Rating
E1	80	64	C-2
E2	10	10	C-1
E3	30	20	C-3
E4	20	20	C-1

	Authorized	Available	MOS Qualified
MOS1	80	80	80
MOS2	20	6	4
MOS3	30	30	30
MOS4	20	4	2

TABLE 1

By the present system readiness would be evaluated as:

Overall Equipment Readiness:	C-2
Available Strength Readiness:	C-2 (80%)
MOS Qualified Strength Readiness:	C-2 (77%)
Overall Personnel Readiness:	C-2

A C-2 rating is quite respectable. However, this rating does not represent the actual capability of the unit, since the shortages of equipment do not correlate with the shortages of personnel. Therefore, while the present system implies that 114 of 140 pieces of mission essential equipment and 120 of 150 personnel can be employed in accomplishing the mission, the actual figures are 91 (C-3) and 94 (C-4) respectively. Assuming readiness can be equated to a percentage of assets available,

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[1] To clarify the example MOS1 could be a forklift operator and E1 a forklift or MOS2 could represent the TOW gunner and assistant gunner and E2 the TOW system. Obviously there might be more than one operator for each piece of equipment and some operators might be considered team members for different items of equipment.

this is a change from C-2 to C-4.[2]

This discrepancy results because the present system looks at personnel and equipment independently and does not adequately consider the relationship between the elements of readiness. A weapon or other piece of equipment is of little use without a trained operator. While lack of equipment, for example, may be used as a reason for poor training status, the present system does not focus on the synergism of the key elements. To relate resources to mission capability the system should combine personnel with individual items of equipment to form "mission cells."

MISSION CELLS

A mission cell consists of trained personnel with appropriate equipment in an operating condition to accomplish a task essential to the accomplishment of the unit's mission. Different type units will have different types and numbers of mission cells. An example of a mission cell in an infantry company could be a rifle squad; in a transportation truck company, a driver with tractor and semitrailer; in an ammunition transfer company, a forklift with operator; and in an armor company, a tank with crew. The key is that if any part of the mission cell is missing, not operating, or the personnel not adequately trained, the mission cell cannot perform its assigned task and the unit's ability to accomplish the mission is reduced. Hence, we have combined people, equipment, equipment operating status, and training.

The number and type of mission cells would be doctrinally established for each type of organization. In addition, the doctrinal definition of each mission cell could be modified for specific mission focus if desired.

This discussion is not intended to imply that elements of the unit that do not directly accomplish some part of the final mission are insignificant and should not be considered in computing unit readiness. Elements such as the unit supply room, unit motor pool, or field mess play an important role in preparing and sustaining operations but must be considered in that sustaining role. There must be a distinction between combat support and combat service support functions that sustain the unit's mission and the same activities that are the mission. For example a unit supply room or PLL sustains that organization's mission but a direct supply unit has a mission to provide supplies. A unit motor pool sustains a different mission and a

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[2] Percentage was computed by comparing a possible total of 290 people and items of equipment against a reported availability of 234 (81%) by the present system and 185 (64%) available by linking people to their assigned piece of equipment.

direct support maintenance unit may perform similar tasks but performs them as its primary mission. A signal company provides communication as its primary mission while a company signal section sustains the company's mission.

A method to measure the impact on mission readiness of mission cells and sustaining cells was discussed in a May 1983 article in Military Review entitled "Logistics Unit Effectiveness Modeling."

To illustrate this concept, consider the original example and define three mission cells (MC) and one sustaining cell (SC).

* MC#1 consists of one MOS1 equipped with one E1;
* MC#2 consists of two MOS2 equipped with one E2;
* MC#3 consists of one MOS3 equipped with one E3;

and

* SC#1 consists of one MOS4 equipped with one E4.

Using the percentage system presently used to compute personnel strength, readiness which was C-2 under AR 220-1, would now be computed as C-3 for immediate mission capability and C-4 for sustainability as shown in Table 2.

	Cells Authorized	Cells Available	%	C-Rating
Mission Cells				
MC#1: MOS1/E1	80	64	80	C-2
MC#2: MOS2/E2	10	2	20	C-4
MC#3: MOS3/E3	30	20	67	C-4
Overall	120	86	72	C-3
Sustaining Cell				
SC#1: MOS4/E4	20	2	10	C-4

TABLE 2

Note that this system provides a more realistic description of the unit's present capabilities. In practice raw data from the unit would be input into a mathematical model, unique to each unit. Back up data would assist in identifying the specific shortages that would offer the greatest marginal improvement in mission readiness.

This system reduces the workload presently placed on unit personnel, since the data could be extracted directly from automated personnel, supply, and maintenance systems. An added benefit is that raw data is still available for use at the wholesale level. The final output is still subject to interpretation and mature judgment, so the commander has not lost any of his prerogatives.

BATTLE FOCUS

The present readiness reporting system measures the ability of type organizations to perform a generic mission. As a result the organization may expend a tremendous amount of resources to fix something that is not important to the specific mission at hand. For example the organization may be fixing a truck that will be left in the rear in a specific scenario at the expense of fixing other equipment that is critical to the scenario. The truck should be fixed but not as a priority over other equipment that may be more important to the mission. Battle Focus must guide the logistical effort as well as the training effort.[3]

To demonstrate how Battle Focus can be applied to the unit readiness reporting system, consider a special forces group that has four doctrinal missions: direct action, foreign internal defense, strategic reconnaissance, and unconventional warfare. The present system does not link the vast amount of detail on personnel and equipment to each of the missions that the unit is expected to perform, but the linkage can be achieved through the application of the mission cell and sustaining cell.

Consider a mission cell for a special forces group, the "A" Team. The operational detachment A (ODA) will ultimately accomplish one of the four doctrinal missions. Note that each of the missions may require all or only part of the team members and equipment while the remaining equipment may be needed in reserve or not needed at all. Therefore, a different mission cell can be constructed to accomplish each mission and mission readiness computed based on resources available as has been shown. A possible analysis for an ODA is shown in Table 3.

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[3] Battle Focus, as defined by FM 25-100, Training the Force, is "a process to guide the planning, execution, and assessment of each organization's training program to ensure they train as they are going to fight." Battle focus recognizes that units cannot attain proficiency to standard in every task. Therefore, the unit program focuses on the reduced number of tasks essential to mission accomplishment.

ODA 111	Direct Action	Capable
	Foreign Internal Defense	Not Capable - Need two linguistic qualified personnel.
	Strategic Reconnaissance	Not Capable - Need two night vision goggles
	Unconventional Warfare	Not Capable - Need two linguistic qualified personnel.

TABLE 3

Consolidating this information for each team in a special forces group would result in information as shown in Table 4.

Unit	# of ODAs	Mission	# Mission Capable
1st Bn	18	Direct Action	16
		Foreign Internal Def	14
		Strat Recon	16
		Unconventional Warfare	18
2nd Bn	18	Direct Action	18
		Foreign Internal Def	14
		Strat Recon	14
		Unconventional Warfare	15
3d Bn	18	Direct Action	12
		Foreign Internal Def	16
		Strat Recon	11
		Unconventional Warfare	17
Group	54	Direct Action	46
		Foreign Internal Def	44
		Strat Recon	41
		Unconventional Warfare	50

TABLE 4

As opposed to the present readiness system, this method allows the group's capabilities to be easily compared to the group's missions as specified in operations plans or specific operations orders, as shown in Table 5.

	ODAs Auth		ODAs Msn Req	ODAs Msn Capable
Group	54	Direct Action	48	46
		Foreign Internal Def	18	44
		Strat Recon	54	41
		Unconventional Warfare	9	50

TABLE 5

Note that these mission requirements add up to more than 54, which is plausible. Some of the missions may be follow-on missions or, even more likely, there are insufficient resources to accomplish all tasks.

This method immediately identifies the unit's shortfalls in accomplishing direct action and strategic reconnaissance missions. To remedy the shortfall the commander can

* improve readiness by correcting the specific equipment, personnel, and training shortfalls. If additional resources are not available then equipment may be transferred from sections within the organization where it is excess. Note that "excess" in this case pertains to the particular mission and not to the organization's equipment authorization. This method has successfully been applied in the present system by transferring equipment from requirements classified as equipment readiness code (ERC) B or C to higher requirements classified as ERC A.

* negotiate mission priorities with the theater war planners.

A key feature of this system is that the commander can immediately identify what is "broken" and focus his energies on the mission stoppers.

The mission requirements, although contrived, are representative of those in a high intensity conflict in a developed theater such as Europe. In a less developed theater such as Latin America, mission requirements for a special forces group might be as shown in Table 6.

	ODAs Auth		ODAs Msn Req	ODAs Msn Capable
Group	54	Direct Action	18	46
		Foreign Internal Def	54	44
		Strat Recon	36	41
		Unconventional Warfare	36	50

TABLE 6

When comparing unit readiness to the requirements of a low intensity conflict, a commander would derive a much different focus for training and allocating resources than when he compares the same readiness to the requirements of a high intensity conflict scenario.

This method also allows a commander to quickly assess his ability to accomplish a "no-plan" mission that differs from his existing missions.

While many operations plans do not lend themselves to this comparison, in many cases they could, and improving those plans may be an additional benefit of adopting this system.

APPLICABILITY

While special forces is used as an example, the system is applicable to all organizations. The key is to identify the mission cells and the sustaining cells. Examples of mission cells and sustaining cells for different types of units are shown in table 7.

UNIT	MISSION CELL	SUSTAINING CELL
Aviation	Operational aircraft with crew	Mechanic with equipment
Infantry	Infantry platoon	Field mess section
Transportation	Tractor and semi-trailer with driver	Repair parts specialist

TABLE 7

DEPLOYABILITY

Because of the many unknowns it may not be practical or efficient to measure deployability to the same quantifiable degree as readiness rates of key pieces of equipment for example. However, it is essential that some indication be gained of the ability to deploy the unit if the commander is to assess his ability to accomplish the mission. This indication may subjective or objective as long as it identifies and assesses shortcomings that reduce a unit's ability to deploy.

TRANSITION

Adoption of this system will possibly result in a perceived drop of overall readiness rates as has happened previously. Commanders lowered the readiness rates because authorization of modern equipment preceded the fielding of that equipment. Common sense eventually prevailed and the system was modified to comply with reality.

Common sense must apply to this transition as well. Users of the data must be educated to properly interpret the results. Possibly two system should exist. The proposed system would support the commanders in the field while the present system, without the commander's comments, could be retained in a simpler form to provide input to the whole sale logistical and personnel system.

SUMMARY

The proposed system uses cells of personnel and equipment to determine mission capability. The aggregation of all mission cells in conjunction with sustaining cells provides an overall unit readiness picture that can be compared to mission requirements.

This system requires no more information than the present system, and since the analysis is done above the company level, the workload of the company commander is reduced. What this system does do is

- provide the commander at each level with the appropriate analyzed information upon which he will make a decision, rather than raw data that does not readily integrate personnel with training and equipment.

- allow the commander to focus his primary attention on mission stoppers.

- compare the readiness to the specific mission.

ARMY MATERIEL COMMAND (AMC) RESOURCE VERSUS READINESS

Wilson E. Heaps
Lisa K. Collidge
Gary L. McPherson

Presented at AORS XXVIII

OCTOBER 1989

#161

TITLE: Army Materiel Command (AMC) Resources to Army Materiel Readiness Study .

AUTHORS: Wilson Heaps and Gary McPherson

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

The Army Materiel Systems Analysis Activity (AMSAA) has been participating with a Headquarters (HQ) AMC study group with the goal of objectively quantifying relationships between AMC resourcing levels and Army materiel readiness. In the past, many studies have been performed by all the services to identify the relationships between cost and readiness; however, few quantifiable and useful relationships have been found. A major portion of the AMSAA contribution to the resources to readiness study effort has been analysis of relationships at the individual weapon system level. Two approaches have been taken in analyzing resource to readiness relationships of individual weapon systems.

One approach has been to characterize the association between sustainment costs and operational readiness data for four individual weapon systems. Yearly weapon system sustainment costs were obtained from baseline cost estimate (BCE) reports and actual expenditure data. Historical operational readiness data for each weapon system were extracted from the Readiness Integrated Data Base (RIDB) which serves as a repository for readiness status reports on fielded weapon systems. Regression analysis was conducted with these data. Preliminary results indicate that no statistically significant relationship between the sustainment cost and readiness data sets can be described using regression analysis.

The second approach involves the analysis of the relationship between support resource levels and end item operational availability (Ao) for three major weapon systems by integrating the outputs of two different support resource analysis/evaluation models. The Selected Essential-Item Stockage Availability Method (SESAME) model was used to analyze the relationship between retail level support costs and the Ao of each weapon system. Input for the SESAME analysis was based on detailed logistics pipeline parameters and component failure factors which were derived from available actual data and engineering estimates. By varying the wholesale fill rate parameter it was possible to analyze the impact of wholesale-level supply support responsiveness on retail-level support cost and Ao. It was observed that at higher weapon system Ao rates, wholesale fill rate changes result in significant retail-level cost changes or

minimal Ao changes; while at low Ao rates, wholesale fill rate changes have minimal impact on retail-level cost or a significant impact on Ao. The Supply Performance Analyzer (SPA) model was used to identify the wholesale - level costs associated with the wholesale fill rate changes analyzed with the SESAME model. The wholesale costs obtained from the SPA methodology were based on actual historical supply pipeline performance data. The wholesale-level costs derived from the SPA model were then combined with the retail-level costs derived from the SESAME model to obtain total support cost at various wholesale fill rates. This process provided the means for describing relationships between total support cost and readiness (i.e. Ao) at varying wholesale fill rates.

#163

TITLE: Incorporation of Combat Damage Requirements in the Combat ASL

AUTHORS: Meyer Kotkin, Clark J. Fox, and Eric A. Snyder

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

The current procedures used by the Army to establish division-level Authorized Stockage Lists (ASL) do not consider requirements for combat damage repair parts. AMSAA analysts have developed a methodology to estimate the combat damage requirements for the ASL. This methodology is based on combat damage demand rates which are estimated from the Sustainability Predictions for Army Spare Component Requirements in Combat (SPARC) data. The combat damage demand rates for individual parts are input to a stock optimization model which produces the least cost set of parts to achieve a specified availability goal. Results are available for the M1 and M60A3 tanks, the M2 and M3 Bradley Fighting Vehicles, and the UH-60A, AH-1S, and AH-64 aircraft. These results show that availability goals in combat can be attained only if combat damage repair parts are provided in the ASL. The cost, weight, and volume of these parts are also calculated. Additional analyses shows the impact on availability if the combat damage stock is taken out of the ASL and moved behind the division.

#146

TITLE: National Guard (ARNG) Readiness Improvement Initiative (RII)

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ABSTRACT:

An RII was undertaken with the ARNG by the USAMC Materiel Readiness Support Activity (MRSA), Readiness Division (AMXMD-ER), 30 Jun 88. The action was a result of a study decline in ARNG fully mission capable (FMC) rates since 1980. At the close of the 2d Qtr FY 88, the overall FMC rate for the ARNG was 88 percent, with 46 percent of all states and territories below the Department of Army (DA) goal of 90 percent FMC.

The objective of the RII is to assist in identifying and implementing actions to increase and sustain the A5WG's FMC rate above the DA goal. The approach is to use readiness reporting data, from the Readiness Integrated Data Base (RIDB) at MRSA, to identify and rank reportable items and states according to their impact on the overall ARNG FMC rate. R-card information, contained on the back of the DA Form 2406, is used to identify the systemic cause of not mission capable time for the top targets of opportunity for readiness improvement. Results of the data analysis are then verified with the state Surface Maintenance Manager, and coordinated with Headquarters, US Army Materiel Command, its major subordinate commands, and the National Guard Bureau. All work together to develop and institute improvement actions. Analysis techniques developed during the RII are being added to the RIDB, and readiness management reports are provided to the ARNG 54 states and territories and the NGB each quarter.

#104

TITLE: Munitions Initiative - Asset Sustainability Model

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ABSTRACT:

The Munitions Initiative - Asset Sustainability Model is a heuristic rule-based model that is used to satisfy worldwide ammunition inventory assets to meet projected peacetime and combat requirements. This model was developed to assist the Single Manager for Conventional Ammunition (SMCA) to provide inventory assessments to the Deputy Chief of Staff for Ammunition. The model follows logic to satisfy ammunition requirements in accordance with the Department of the Army Master Priority List (DAMPL). A complete distribution plan can be developed that shows the Army's readiness sustainability year by year considering peacetime actions. These actions include procurement deliveries, renovation, retrograde, and call forward.

#103
TITLE: Integrated Assessment Models

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ABSTRACT:

The Integrated Assessment Models are a collection of computer models that were developed to satisfy ammunition assessment requirements. The models can be integrated in an ordered manner to provide a means for assessing many facets of the ammunition logistics system. They assist the Single Manager for Conventional Ammunition (SMCA) in managing the complex interdependencies involved in the distribution of Class V ammunition from CONUS depots and production facilities to the overseas theaters during mobilization.

The model system is driven by an ammunition demand funct·) (time-phased ammunition requirement) that is derived from threat analyses of various worldwide combat scenarios and their projected weapon densities and firing rates. The system consists of five modules. The first module is a production requirements determination module. It determines item shortfalls from wholesale inventory and identifies production requirements for the required items or reasonable substitutes. The second module is a projected asset update system. It develops future asset postures considering training requirements, retrograde shipments, peacetime losses, maintenance, renovation, and anticipated production; and projects future inventory asset posture for CONUS and OCONUS. The third module is a production allocation module. Itself consisting of five modules, this system determines the extent to which the ammunition production base can contribute during a mobilization condition. The fourth module is the ammunition distribution system. This module develops time-phased distribution plans for ammunition from CONUS storage facilities and ammunition plants to CONUS ammunition supply points for use during mobilization. The fifth module is the conventional ammunition readiness evaluation system. This module consolidates requirements and computes shortfall requirements. It computes and assesses conventional ammunition readiness by time period and generates logistics readiness/sustainability reports.

The Integrated Assessment Models play an important role for the SMCA to assess many aspects of the logistics system including inventory, transportation, distribution, readiness postures, mobilization planning, and depot and port capabilities of Class V ammunition.

#162
TITLE: Operating and Support Cost Reduction

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ORGANIZATION: US Army Materiel Systems Analysis Activity
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ABSTRACT:

As part of a combined Army Materiel Command and Training and Doctrine Command initiative to significantly reduce the Army's operating and support cost for materiel, the US Army Materiel Systems Analysis Activity has examined the Army's Field Exercise Data Collection database to identify the Class IX components with the most impact on repair and replacement costs. Field exercise component replacement data for several major weapon systems were combined with repair cost information from various sources to estimate a Class IX cost. Subsequent rankings of components by total repair and replacement costs were then prepared to determine which components should be targeted for operating and supports cost reduction techniques. Analysis of several weapon systems indicated that a large percentage, typically 70-90 percent of the Class IX component repair and replacement costs were associated with the top ten components.

The entire contents of this paper are UNCLASSIFIED

TANK AMMUNITION COMBINED ARMS RESUPPLY MODEL

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1. PROBLEM.

a. The United States Army is faced with the problem fielding an armor force that is capable of defeating a Soviet armor force that is superior in numbers and also quickly approaching parity in capability. Sufficient amount of ammunition is required to defeat the larger Soviet force. The ammunition requirement of the armor force structure are comprised of many factors. One of these factors is the number of main gun rounds which comprise the tanks basic load. The basic load for a tank is stored in two different locations. Part of the basic load is stored on board the tanks, "stowed load", and the remainder of the basic load is stored on board the battalion ammunition resupply trucks. These ammunition resupply trucks also provide the battalion with the capability to resupply the tanks with ammunition once the basic load is expended.

b. The size of the basic load, stowed load, and the number of resupply trucks required is a function of many different parameters. Several of the major parameters which may be considered when ammunition requirements are being established are as follows:

(1) Force ratios. The Blue versus Red force ratio will influence the amount of ammunition that the Blue force needs. The smaller the Blue force is as compared to the Red force the larger is the amount of ammunition which will be required by the Blue force.

(2) Unit Missions. Different unit missions will require different amounts of ammunition. For example, a defensive mission would be expected to require a greater amount of ammunition than a offensive mission because the Red force would be attacking with a three to one advantage in vehicles.

(3) Red Combat Losses. The number of vehicles in a Red force that must be destroyed to stop an attack or to displace a defending Red force will influence the ammunition requirements. The larger the number of Red vehicles which must be destroyed the greater amount of ammunition that will be required.

(4) Contribution of Other Combat Arms. The contribution made to the battle by the other combat arms will determine how much ammunition the armor force will need. The greater the contribution the armor force makes to the battle the larger the amount of ammunition required by the armor force.

(5) Lethality of Tank Rounds. As tank rounds become more lethal the amount of ammunition required to defeat the same number of threat would be expected to decrease.

(6) Crew Training. The quality of the tank crew training will influence the amount of tank ammunition that is required. The greater number of false targets, and dead targets which are engaged by the tank crew the greater will be the ammunition requirements. Also, the more targets which the crew engages and misses the greater will be the ammunition requirements.

(7) Maintenance of Supply Lines. The ability of the supply system to deliver ammunition will affect the stowed load and basic load requirements. As the supply lines become stable and able to deliver ammunition the armor force will become less dependent upon its basic load. There is an associated risk with dependance upon the supply system for ammunition requirements. The resupply vehicles are vulnerable to artillery, suffer maintenance failures, and may become lost while en route.

(8) Tactics. Various tactics employed by the Blue force will vary the distribution of ammunition usage between the Blue units. Units placed in a reserve role will not be expending ammunition at the same rate as units which are committed to the battle.

(9) Operation Tempo. The higher the operation tempo the greater it would be expected for the ammunition expenditure to be.

(10) Engineering Constraints. The number of rounds that can be stored on board a tank or on a resupply vehicle is constrained by the size of the vehicle. The portion of the basic load which is not stored on the tanks is stored on the battalion resupply trucks. The increase in size of tank ammunition reduced the number of rounds that can be stored on board the tank. This increased the truck requirement to make up for the storage space that was reduced on the tanks.

(11) Attrition. As the Blue tanks and resupply vehicles are attrited the remaining vehicles will have an increase in responsibility to pick up the load which was previously carried by the destroyed vehicles.

2. DILEMMA. The United States Army Armor School (USAARMS) Directorate of Combat Developments (DCD) is responsible for establishing Required Operational Capabilities (ROC) for armor systems and also documenting the requirements for the Armor force structure.

a. Because of budget/funding limitations the Army can not afford to design equipment and a force structure that is based upon a worst case scenario. The Army must design a force that is capable of completing its missions with an acceptable degree of risk.

b. As exemplified by the eleven parameters listed above the resolution of this dilemma is a complex problem. The Tank Ammunition Combined Arms Resupply Model (TACARM) was developed to gain insights into how these various parameters effect mission accomplishment along with the attendant risks.

3. **FRAMEWORK.** TACARM is comprised of three major parts, (input, model algorithm, and output). The battle scenario is "scripted" by the values that are assigned to the input parameters. By scripting the scenario the results of the battle are predetermined. This technique provides the analyst a method to obtain the desired battle outcome for any combat scenario. Analysis can then be performed to determine the effect that various resource limitations would have on the battle outcome.

a. **INPUT PARAMETERS.** A wide range of scenarios and battle outcomes can be analyzed using TACARM. The values assigned to the input parameters determine the outcome of the "scripted" scenario and makes TACARM a very flexible model. The following are the major input parameters of the model:

(1) Rounds/kill - This is the mean number of rounds fired for each Red vehicle killed. The value assigned accounts for probability of hit, probability of kill, firing at false targets, firing at dead targets, etc..

(2) Percent Red kills - The percent of the total starting number of Red vehicles that are killed.

(3) Percent Blue kills - The percent of the total starting number of Blue vehicles that are killed.

(4) Percent Red killed by Blue tanks - The percent of Red vehicles that are killed by Blue tanks.

(5) Percent resupply - The percent of the starting stowed load that will be resupplied between the regimental battles.

(6) Stowed load - The number of rounds that the tank can carry.

(7) Order of battle - The starting Blue and Red force structure and the number of regimental battle that will be fought.

(8) Concept of operations - The task force organization and the tactical concept for the Blue and Red forces.

b. MODEL ALGORITHM.

(1) The TACARM model is both deterministic and stochastic. The combat outcome is deterministic. The results of the combat are determined by the values which are assigned to the input parameters. The model stochastically allocates the available resources while trying to achieve the desired combat results.

(2) Several key assumptions are made in the model. The first assumption made is that there is only one category of tank loss. All tank losses are catastrophic. The second assumption made is that the battalion commander's and operation officer's tanks are not involved in the shooting battle and that the tank company commander's and executive officer's tanks are involved 100 percent in the shooting battle. This assumption balances out between the four tanks the amount of time which is spent fighting the battle and the time which is spent performing command and control.

(3) The various Blue combat systems are each responsible for engaging a portion of the Red combat vehicles in a regiment. Table 1 shows an example of how this responsibility may be divided among the different combat arms. These percentages may be varied to perform sensitivity analysis.

TABLE 1 SHARE OF TARGETS
MOTORIZED RIFLE REGIMENT

	TANK	BMP/CS
ARMOR	71%	60%
INFANTRY	12%	23%
FIELD ARTY	5%	5%
ENGINEER	5%	5%
ATK HELO	5%	5%
CAS	2%	2%

(4) Using the data from Table 1 and several additional factors the number of targets that Blue tanks are responsible for killing can be calculated. The model considers the reliability, availability, and maintainability (RAM) of the Red vehicles when calculating the number of Red vehicles to be engaged. The total number of available Red vehicles is reduced by the number of vehicles that are expected to be RAM failures. Also the total number of vehicles to be engaged is reduced by the goal that the Blue force desires to attrite the Red force to. An example calculation of the total number of Red tanks and BMPs/combat support vehicles from the MRR which the Blue force is responsible for killing is calculated in Table 2.

TABLE 2 ARMOR RESPONSIBILITY

	VEH #		RAM		GOAL		SHARE		
TANKS	40	X	(1-.15)	X	.70	X	.71	=	17
BMP/CS	164	X	(1-.15)	X	.70	X	.71	=	<u>59</u>
								TOTAL	76

(5) Each Red regiment which the Blue force fights may be thought of as an independent regimental battle. The length of a regimental battle is expected to last between one and two hours. During this time the intensity of the battle will vary. There will be a beginning, peak, and an end of the battle. These three parts of the battle and the associated battle intensity may but not necessarily follow a normal curve as in Figure 1. The model breaks the regimental battle down into five minute increments. This allows a snap shot of the regimental battle to be attainable every five minutes. The amount of ammunition expended twenty minutes into the battle is an example of information that can be collected.

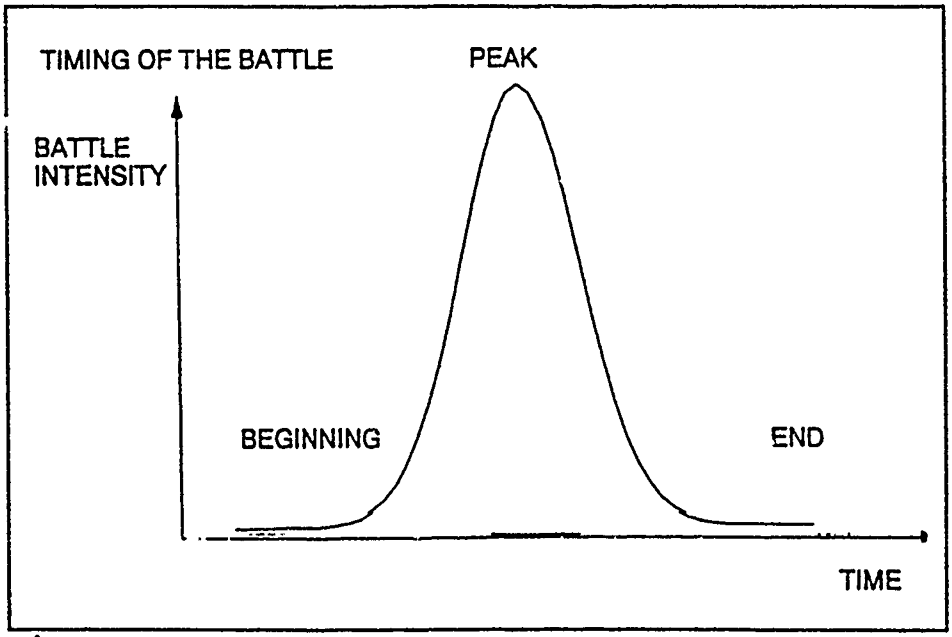

Figure 1 BATTLE INTENSITY

(6) Assuming the battle intensity profile follows a normal distribution (any other distribution could have been chosen), then the Red losses would be distributed normally over the duration of the regimental battle. Figure 2 shows the distribution of loss[illegible]or the regimental battle in five minute increments. The length of a regimental battle is an input parameter which may be changed by the user during the initial setup of the model. In this case the regimental battle is one hour in length. Although the losses are computed in the model to fit a normal distribution, because the vehicle losses are stochastically allocated to the surviving vehicles the actual losses may not exactly fit a normal distribution.

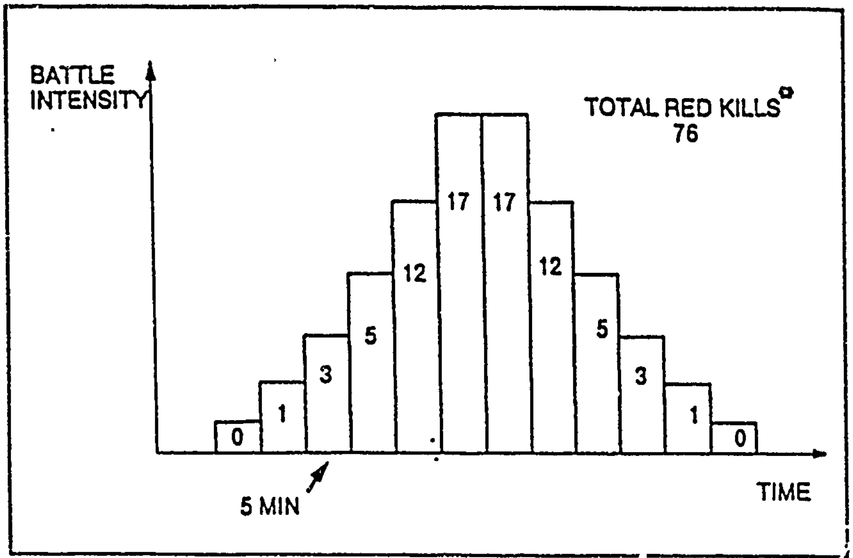

Figure 2 DISTRIBUTION OF LOSSES

(7) Depending upon the average number of rounds per kill input as a starting parameter the ammunition expenditure would follow the distribution of Red vehicle losses. Figure 3 shows the ammunition expenditure for a regimental battle with four rounds per kill as the average number of rounds required to kill a Red vehicle.

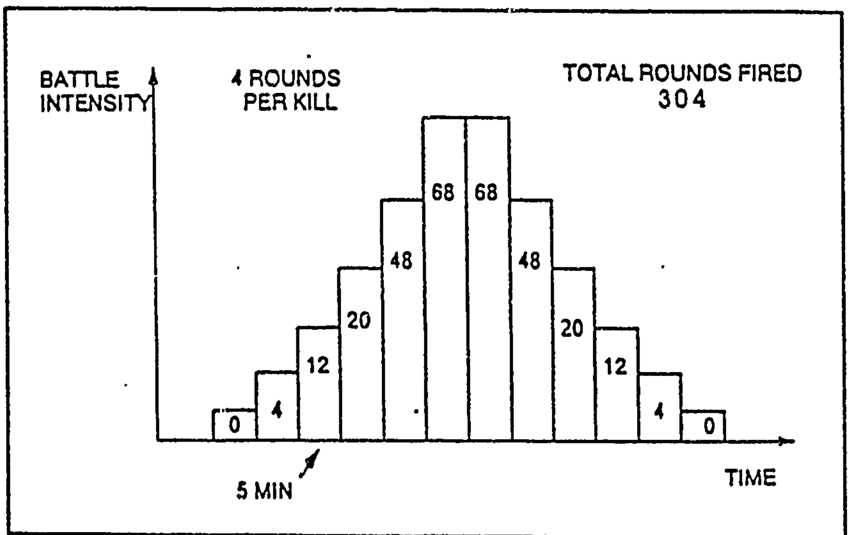

Figure 3 AMMUNITION EXPENDITURE

c. OUTPUT.

(1) The model output provides information in three different areas. The first and the major area provides the status on various tank ammunition parameters as follows:

- number rounds remaining on alive tanks
- number rounds lost on destroyed tanks
- number of tanks that ran out of ammunition
- number of rounds expended per tank
- number of rounds resupplied

(2) These results are analyzed to provide information which shows how varying the input resources effects the status of the various ammunition outputs. The output will also provide information on the tactical disposition of the Blue force at the end of the battle. This information reflects the effectiveness of force resulting from the input resource values. The third piece of output data provides information on which vehicles were killed during the battle.

4. EXAMPLE PROBLEM.

a. INPUT PARAMETERS. The first step in preparing the model for execution is the selection of the values for the key input parameters. These values may be varied by the model user so that sensitivity analysis may be done by the user in various area of interest to the user. The following values were assigned to the input parameters for the example run.

(1) Blue Losses - 30%

(2) Red Losses - 70%

(3) Red Force Vehicles Destroyed by Blue Tanks:
Red Tanks - 71%
Red BMP/CS - 60%

(4) Resupply Available - 80%

(5) Amount of Stowed Load - 40 Rounds

(6) Average Number of Rounds Per Kill - 4

b. SCENARIO.

(1) The second step in preparing the model is the "scripting" of scenario. In this example problem the Blue task force comprised of three tank companies and one mechanized infantry company is defending against two Red regiments [Figure 4]. The scenario is scripted based upon the parameters of METT-T (Mission, Enemy, Troops available, Terrain, and Time). An example of how the Blue task force may be task organized and how

the commander positions his forces is shown in figure 5. The units may be positioned according to the commanders scheme of maneuver.

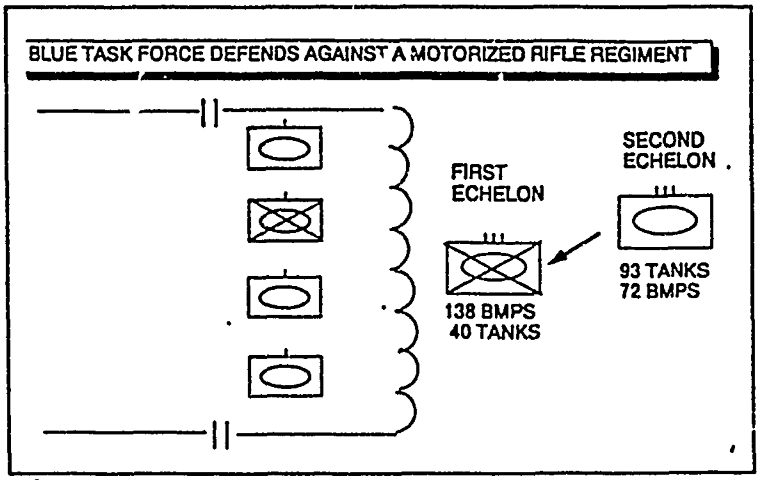

Figure 4 BATTLE SCENARIO

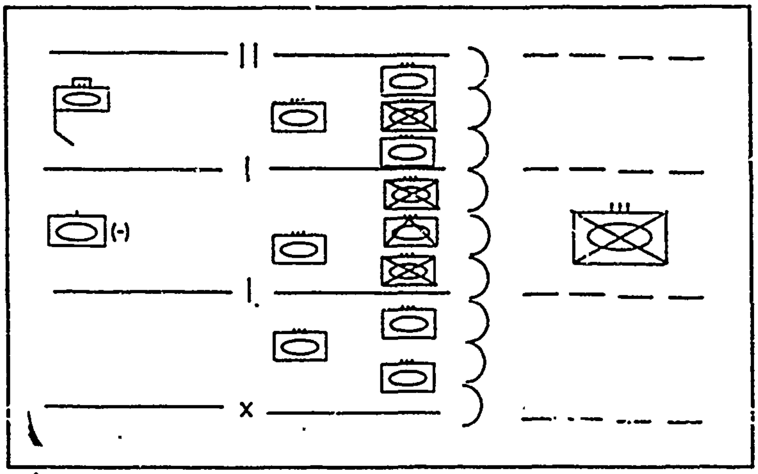

Figure 5 TASK ORGANIZATION

(2) The final step in scripting the scenario is the scheduling of the battles. Length of the regimental battles, time between the regimental battles, and the regimental battle intensity profile can be varied as inputs to fit a desired scenario. For this example the regimental battles are two hours apart and each battle lasts one hour. The battle intensity profile is chosen to follow a normal distribution as in Figure 1.

c. EXAMPLE PROBLEM RESULTS.

(1) Following the first regimental battle the following are examples of three results which provide information about the Blue force ammunition status. The mean number of rounds

remaining on each alive Blue tank was twenty-five rounds. This provides an estimate of the amount of ammunition required for each tank to return it to a full stowed load. There was a mean of thirty rounds lost on each Blue tank destroyed. The logistic system may use this information for planning the amount of ammunition needed to be pushed forward to replace the destroyed ammunition. During the first regimental battle zero of the Blue tanks ran out of ammunition. The Blue commander may use this information to determine if emergency resupply is required during the battle. In this scenario, emergency resupply does not appear to be needed during the first regimental battle.

(2) After the second regimental battle was completed the tank ammunition status of the Blue force is provided as output. The mean number of rounds remaining on the alive tanks was twenty rounds, and the mean number of rounds lost on tanks which were destroyed was twenty-two rounds. This information provides the logistic system with data required to plan the resupply operations. Two Blue tanks ran out of ammunition during the second regimental battle. Again, it appears that emergency resupply of ammunition is not required to defeat the Red forces with the input values used in this example.

5. SENSITIVITY ANALYSIS.

a. Three of the key input parameters in the example problem (stowed load, rounds per kill, available resupply) were varied to determine the sensitivity of the Blue vehicles' ammunition status at the end of the battle to variations in these variable values. All other input values remained the same as for the example problem. The range bands for parameters were varied as follows:

(1) Stowed Load on Blue Tanks (20, 25, 30, 35, 40) rounds

(2) Rounds per Kill (4, 5, 6, 7, 8, 9)

(3) Available Resupply (0, 20, 40, 60, 80, 100) percent

b. The mean number of rounds left on surviving tanks after both regimental battles have been completed is shown in Figures 6 and 7. As would be expected, the charts show that smaller stowed loads, decreased amounts of resupply, and higher numbers of rounds per kill will produce a smaller mean number of rounds remaining on alive tanks. Those combinations of parameters which produce a mean of zero rounds remaining reflect the cases were the Blue force did not accomplish its mission. Unless the last remaining round killed the final assigned Red tank, the Blue force ran out of ammunition before it was able to destroy its assigned share of targets.

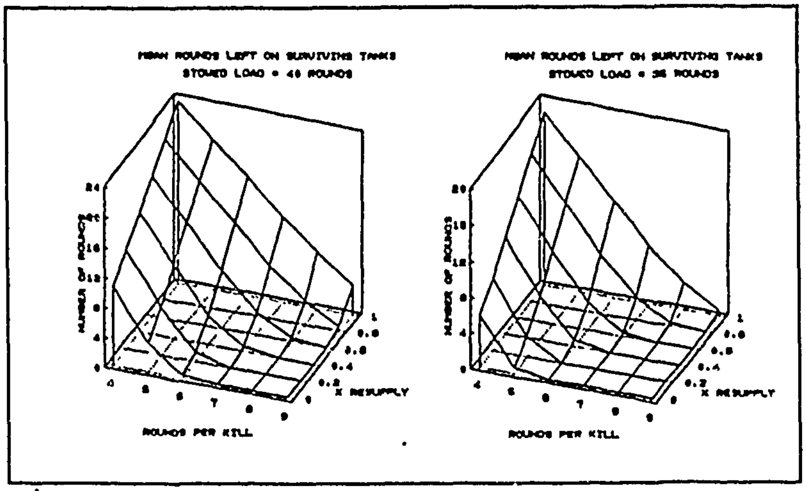

Figure 6 MEAN ROUNDS REMAINING

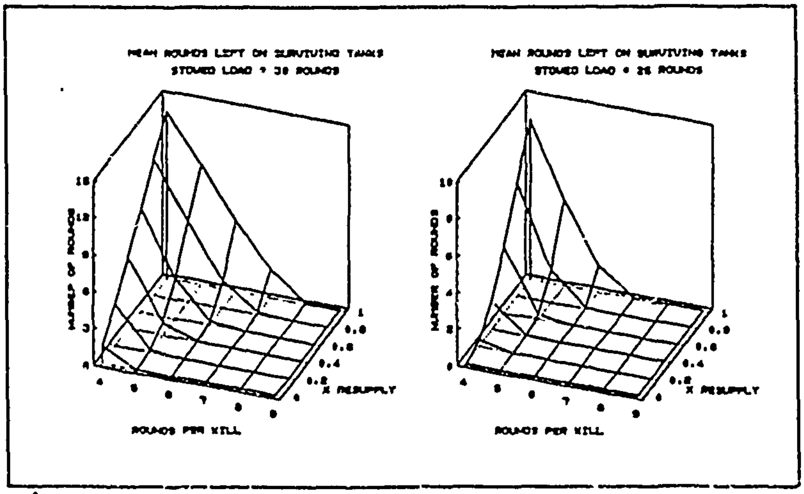

Figure 7 MEAN ROUNDS REMAINING

6. RISK ASSESSMENT.

a. The Army can not afford to design a force that is capable of meeting the "worst" case scenario. With the ever tightening military budget the Army is constrained in the amount and cost of its equipment. The Army is designed to meet a range of "reasonable" scenarios, and accept some risk that it will not be prepared to meet all future requirements. The "reasonable" scenario used in the TACARM model is that the Blue tanks destroy 100% of the Red targets assigned, and that the tanks have at least five rounds of ammunition on board after any regimental battle. An acceptable level of risk is defined as the following:

$$P(\text{TANK AMMUNITION STATUS} < 5 \text{ ROUNDS}) \leq .10$$

b. The goal is to have ten percent or less of the surviving tanks end a regimental battle with less than five rounds remaining onboard. By having five or more rounds remaining onboard after a regimental battle the battalion has greater flexibility with which to respond to changing situations.

c. Figure 8 shows the probabilities, after the first regimental battle, that the number of rounds remaining on the alive tanks is less than five. Since no resupply is performed until after the battle only the stowed load and rounds per kill are variables. In the area marked "Blue Force Did Not Kill Red Systems" not all of the assigned Red vehicles, (76), that the Blue force was responsible for killing were destroyed. The middle band of numbers reflect the cases were the Blue force destroyed all assigned Red vehicles but had greater then 10 percent of the surviving with less than five rounds remaining onboard. In the area marked "Goal Achieved" the Blue force destroyed all 76 assigned Red vehicles and had less than ten percent of the surviving vehicles with less than five rounds onboard. For stowed loads less than 35 rounds and when the number of rounds per kill is greater than five it appears the Blue force will not achieve the stated risk.

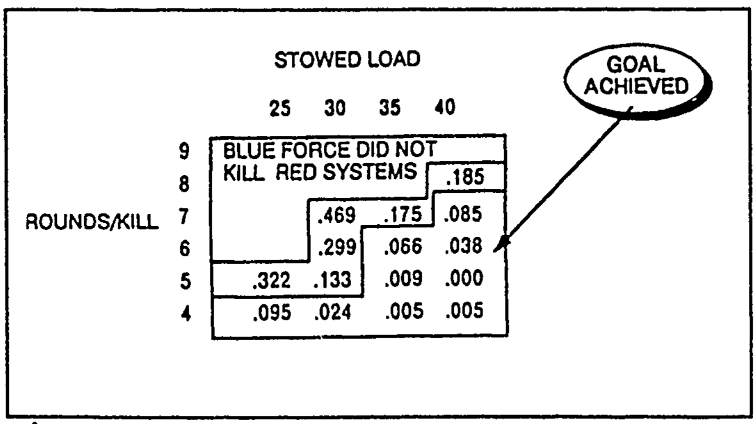

Figure 8 FIRST REGIMENTAL BATTLE

d. Figure 9 shows the risk assessment after the second regimental battle is completed and when the stowed load capacity of the Blue tanks is 25 rounds. Resupply was performed between the end of the first regimental battle and the beginning of the second regimental battle. In this situation the Blue force did not achieve its goal of destroying the assigned number of Red vehicles, and it did not have less than 10 percent of the surviving tanks end the battle with less than five rounds remaining onboard.

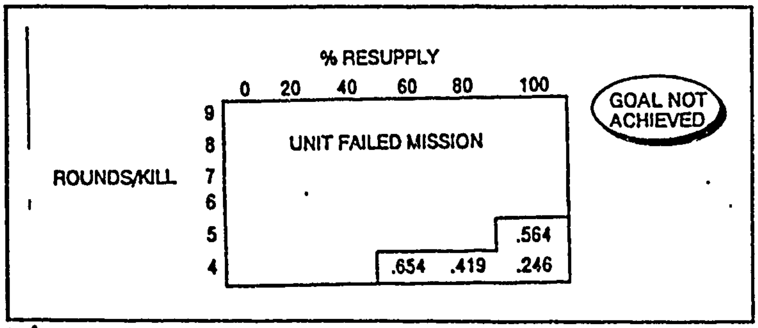

Figure 9 25 ROUND STOWED LOAD

e. In Figure 10 the Blue tanks have a stowed load capacity of thirty rounds. In this situation again the Blue force was not sussessful in accomplishing its mission or achieving the risk goal. Only in the situation were 100 % resupply is available and when the average number of rounds per kill is four was the risk criteria satisfied.

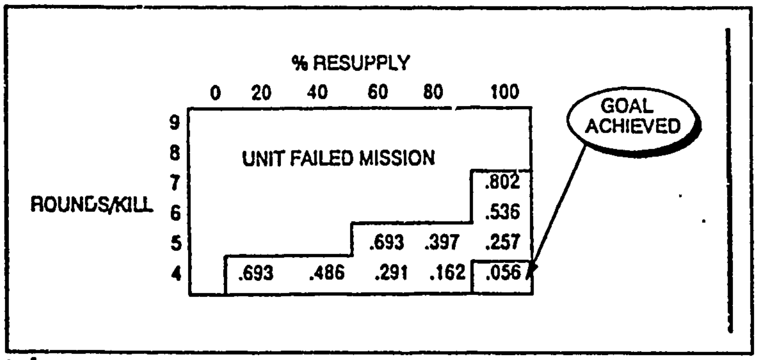

Figure 10 30 ROUNDS STOWED LOAD

f. In Figures 11 and 12 the stowed load is increased to thirty-five and forty rounds respectively. Figure 12 shows that even when the stowed load is increased to forty rounds the Blue tanks do not kill all of the assigned Red vehicles for all of the cases. The risk criteria is satisfied only for high rates of resupply and low averages of rounds per kill.

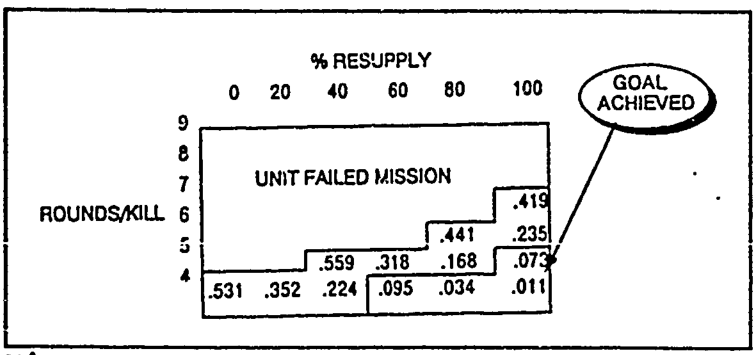

Figure 11 35 ROUNDS STOWED LOAD

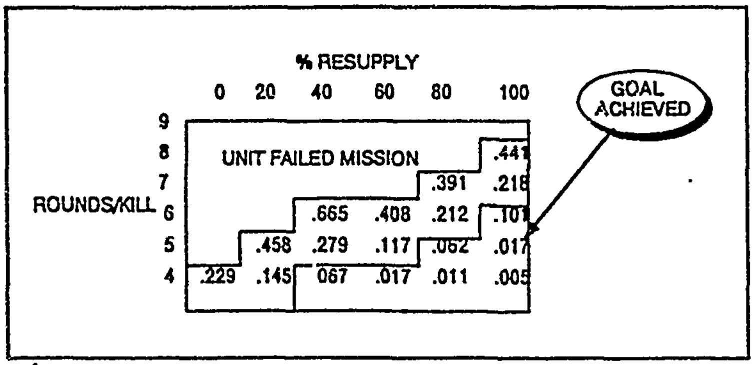

Figure 12 40 ROUNDS STOWED LOAD

7. CONCLUSION.

a. The TACARM model presents a methodology based upon a scripted scenario which may be used in the analysis of acceptable risk in the planning of armor system requirements and the armor force structure. This scripted scenario methodology allows the force designer to set the pre-battle and post battle conditions as given inputs along with the sequence of events during the battle. The model then determines what supplies and combat service support activities are required to support the scripted battle.

b. Future research efforts will concentrate on the ability of organic assets to provide various levels of resupply. A commercial contract has been signed to develop a time-event sequence simulation which will track the activities and status of all combat and resupply vehicles in a heavy brigade. Initially, this effort will track class III and class V assets. The scheduled completion date is April 1990.

Inventory Manager's Assistant (IMA)
Mr. Michael A. Canfield
U.S. Army Missile Command

1. ISSUE. Development of the expert system Inventory Manager's Assistant (IMA).

2. BACKGROUND.

a. The goal of the U.S. Army Missile Command is to develop an expert system to aid inventory manager's while working supply control studies. A supply control study is the heart of inventory management. It depicts the current asset position of spare and repair parts and projects future demand patterns. This process requires vast amounts of data to be reviewed and analyzed. To effectively process a supply control study requires a strong understanding of inventory management. IMA was created with the idea of assisting inventory managers by offering advice on problem issues and automating routine manual tasks.

b. Logistics planning by managers depends heavily on the accuracy and timeliness of the knowledge at hand. When key personnel are not available for advice or guidance, their absence can adversely impact performance. When key personnel are available, their time is constantly divided between their responsibilities and the assistance required by less experienced personnel who depend on them to help solve problems. The IMA will help to alleviate the problem of absence or loss of key personnel by storing the knowledge of the functional experts into a centralized knowledge base and making it available when and where it is needed. In addition to making a functional expert's knowledge more readily available, IMA will allow enhancements in the areas of: training, policy enforcement and continuity, and reduction of human errors.

c. The IMA project is an excellent candidate for expert system technology due to the complex hierarchical decision process and heuristic approach that is employed to correctly process a Supply Control Study.

d. IMA has a high probability of becoming successful due to the vast number of publications and regulations which serve as reference material and the large number of "human experts" who can attribute their knowledge to the project.

e. The development of IMA is controlled by the Materiel Management Directorate, Missile Logistics Center, U.S. Army Missile Command. IMA was developed to run on micro computers operating under MS-DOS and on UNISYS 5000/80 computers operating under UNIX system V using the expert system shell CLIPS.

3. **STATUS.** The development of IMA was initiated 8 May 87 and a prototype system was exported to all Major Subordinate Commands within the Army Materiel Command 6 Mar 89.

4. **POINT OF CONTACT** Further information can be obtained on IMA by contacting either point of contact listed below:

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Title: Logistics Baseline Comparison System

Author: Mr. Jim Wasson, C.P.L.
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Missile Logistics Center

Abstract

Although the Baseline Comparison System (BCS) is an integral part of the Logistics Support Analysis and RAM Rationale Report processes, the logistics supportability parameters of the predecessor and BCS are seldom addressed. Under current recommended guidance, usually only design parameters and Operation and Support Cost estimates are included in the Materiel Developers BCS. What needs to be defined are those logistics parameters, limitations and guidelines currently constraining the new or replacement system. This paper addresses how to develop the Logistics Baseline Comparison System, what it should cover and how it can be effectively used for logistics support analysis. The Army's effectiveness and readiness with new fielded systems, especially during peace time, is governed by the availability of the weapon for use and its support concept (logistics), more then by its performance.

Introduction

Within the Department of Defense (DOD) the directive on Acquisition and Management of Integrated Logistics Support (ILS) for Systems and Equipment (DODD 5000.39) states that in the system's acquisition process "cost, schedule, performance and logistics supportability should be treated as co-equal."(1) This is the pretense to the ILS, Logistic Support Analysis (LSA) and Reliability, Availability and Maintainability (RAM) processes. The Baseline Comparison System (BCS) development activity of an organization is justified and documented as tasks in both Mil-Std-1388-1A (LSA Task 203, Comparative Analysis) and TRADOC/AMC PAM 70-11 (RAM Rational Report Handbook, Materiel Developers Analysis) and referenced in AR702-3 (Army Materiel System RAM).(2,3,4)

The practice of developing a formal BCS is fairly recent (late 1985) and the methodology is still unrefined. However, the principles behind this activity are as old as engineering design itself. When a design engineer starts the design, he/she usually returns to old knowledge, parameters and drawings, modifies and adjusts them, and subsequently predicts the feasibility, constraints and success of the new design.

The approach to developing a BCS within DOD is to similarly identify constraints and limitations, both technological and logistic involved in the required design, and then used as a basis for the new system. These constraints are usually based upon currently available or previously developed technologies. The use of these constraints in the BCS process is initially stimulated by the need to replace or modify a current proposed design to address a current system performance shortfall, to address a predicted threat system, or due to the occurance of a technological breakthrough. The later is not supposed to be the driving justification for a new system, but in some services technology is driving requirements.

Since the true intent of establishing the BCS process is to aid engineering in designing for mission success, the success of the logistics concept is driven by the equality given it versus performance characteristics of the design.

This paper will address the shortfalls observed by the author in the application of the BCS process within the Army. Current BCS practices have subjugated logistics and emphasized the "Sabre Rattling" performance aspects of a new or proposed design.

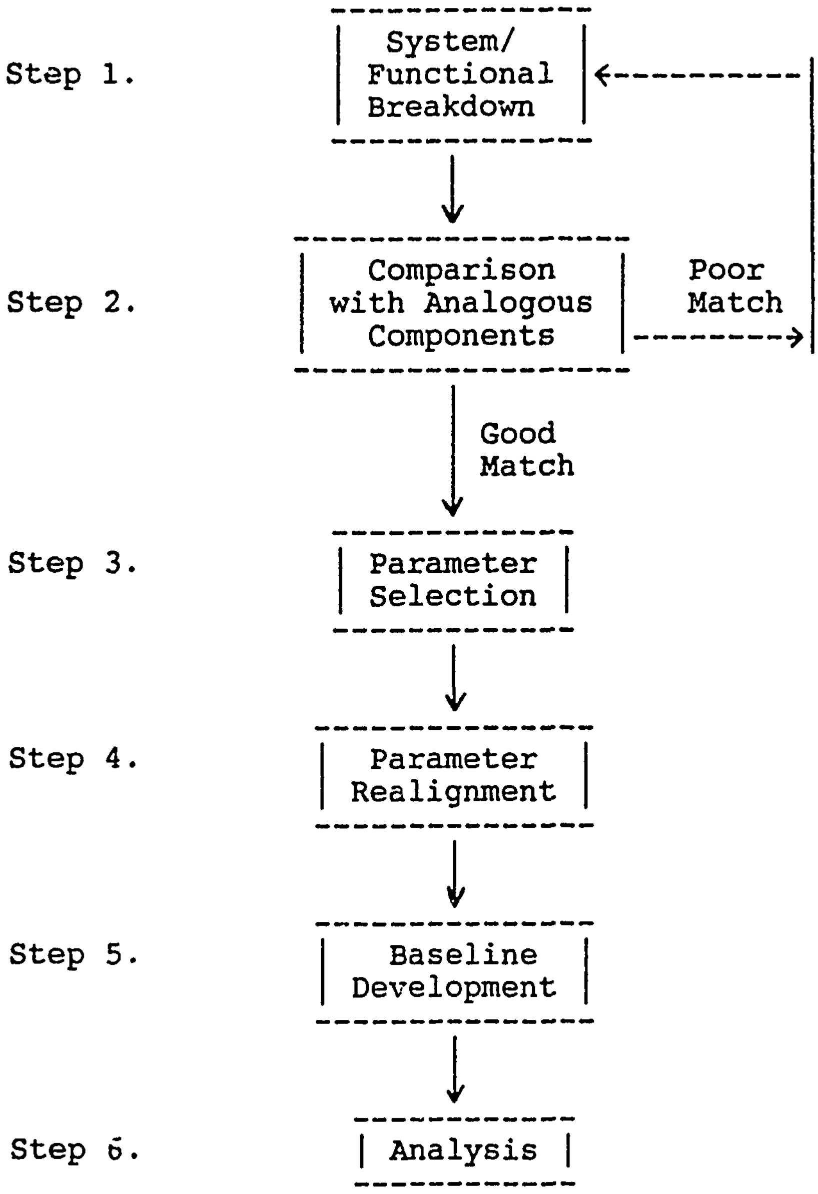
BCS Development Process

The BCS development process usually begins with the start of an system acquisition life cycle, based upon a soldier requirement/shortfall. After the system requirements are defined the preliminary design should be established and partitioned into sub-system requirements. Comparable, current system componentry knowledge and design parameters applicable to the desired design are then theoretically assembled to replicate, as close as possible, the new design. This assemblage (the BCS) will always (should always) fall short of the required need, or why would a new design be necessary.

The BCS is often called a "Frankenstein System", due to the assembling of sometimes previously unrelate components, "Parts is parts." For example, an Air Force radar might be matched with a Navy gun-feed mechanism and mounted on an Army chassis to obtain the desired BCS design performance requirements.

The BCS development procedure formally involves six steps, as illustrated in Figure 1. Each of these steps is a procedure in its self and minimally entails the following:(5)

Figure 1, BCS Development



STEP 1. System/Functional Breakdown - The first step involves taking the system design of interest and breaking it down into components or sub-components. This can be done functionally if insufficient detailed information is known about the system, or the system can be broken down into actual components. Combination of both techniques are also possible. The logistics supportability aspects can also be broken down into areas such as maintenance, supply, test equipment requirements, produceability, etc.

STEP 2. Comparison With Analogous Components - This step involves comparing the various components/sub-components and logistics requirements that were developed with similar items from other previously developed systems. Care must be taken as there is a degree of subjectivity in determining comparibility. If there is a poor match between previous and new design characteristics, possibly a different breakdown amy offer a solution. Also, a different component may be better than the one currently being considered, even if it comes from a non-similar end item. If no match can be found, then the matter can be defered and a prediction performed to supply the data needed in the later steps.

STEP 3. Parameter Selection - Once the components, sub-components and logistics requirements have been selected the system parameters of interest must be chosen. These could be mean time between failure (MTBF), mean time to repair (MTTR), speed, weight, etc. Once a parameter has been chosen, the values of the parameter must be determined. This can be accomplished best by using actual field data.

STEP 4. Parameter Realignment - Sometimes and more often than desired there is not a perfect match between analogous systems/components. This step takes these differences into account. Usually a linear prediction method is used. For example, the MTBF of a new radar set may be the parameter of concern. If it is known that the new radar set is analogous to an existing set that has an MTBF of 500 hours, but the new set is twice as complex, then the new design can be predicted to have a MTBF of 250 hours.

STEP 5. Baseline Development - This step involves tying all the components together into a system. This BCS then becomes the basis of engineering and logistics studies and analysis.

STEP 6. Analysis - This is the step where conclusions are drawn about the new system. The questions of supportability, cost and readiness and the sensitivity of various parameters to fluctuations can also be answered.

Logistics Shortfalls

The previously outlined formal BCS process is very generic and could, if applied effectively, cover all the logistics concerns and constraints before its to late. However, there are some logistics shortfalls in appling the BCS process. These logistics shortfalls are usually due to the fact that performance parameters are considered critical and logistics factors treated as resultant and/or ignored. Parameter Selection (Step 3) is usually the analyst's initial downfall, if the analyst takes the "bottom-line" approach to BCS development and chooses few logistics parameters. The overall thrust of the BCS then becomes will the design perform well, not can it be supported.

Table 1 lists a few of the main logistics areas of concern, which should be of concern to the analyst, but are frequently overlooked early on. All areas of logistics should be addressed but these are the major areas.These include the requirements for maintenance facilities, training of maintenance personnel, test equipment technology available and the availability of contractor versus organic support. Most of those listed are intuitively obvious but are still often ignored. The usual excuses being lack of sufficient information (data) or that these elements are of no real concern at "this" time in the life cycle.

Evaluators for these logistics concern can be both parametric and non-parametric, requiring only subjective analysis. The non-parametric evaluators can be as important to the BCS evaluation as the standard parametric evaluators. Some critical parameters associated with each of the Table 1 areas are shown in Table 2. The effectiveness of addressing logistics in the BCS will be judged based upon how thorough a job the analyst does in addressing the parameters most applicable and important to the new system. These parameters need to be derived just as the performance parameters are derived from existing system data bases, for example: LSA Record Reports, Sample Data Collection for existing systems, Maintenance Action Reports. All these are invaluable sources of logistics data and need to be investigated not ignored.

Table 1, Logistics Concerns and Need/Reason(s) for Concern.

Area of Concern	Need/Reason(s)
Maintenance Facilities	Identifies maintenance facilities needs beyond current demands and projects expansion requirements. If insufficient, costly contractor support or expansion of facilities could override program costs.
Training of Maintenance Personnel	Need to evaluate MOS or civilian training needs. If new MOS is required, personnel may not be available. If special training is added, current MOS need assessments for organic supportability need to be made.
Test Equipment Available	If the need for Test Equipment for the new design requires novel or sophisticated test equipment, the development costs may be to costly and design-to-discard may be a undesireable but necessary option.
Availability of Contractor Support (CLS)	Although usually an interim concept the availability may be necessary for 1 to 5 years. If CLS is used, data may not be available for organic support in the future.
Replaced Inventory Value	The replacement of War Reserves is often ignored in the analysis, but replacement may require controlled attrition rather then wholesale replacement, to be cost effective.
Logistics Interfaces	Equipment shared with other systems currently in use, as well as personnel, may not have the availability to support the requirements of the new system. Hopefully the new system will be more reliable, but workload may shift levels.
Supply Competitiveness	If propriatary design cannot be avoided or deviation from the use of standard parts is required, the replacement spares will inflate due to sole source procurements.

Table 2, Logistics Concerns and Evaluators for Concern.

Area of Concern	Evaluators
Maintenance Facilities	o Operational Availability of Lines o Depot Backlogs o Unused Space, Available vs Needed o Ability to Add Capability (NP) o Ability to Add Personnel (NP)
Training of Maintenance Personnel	o Cost to Set Up Training o Cost per Day to Train o Need for New MOS's (NP) o Hours of Additional Training o Increase in Personnel Needed
Test Equipment Available	o Current TE Adequacy (NP) o New TE Estimated Cost o Development Cost of TE o Discard vs Repair Cost Ratio
Availability of Contractor Support (CLS)	o Cost of CLS, Dedicated or Job-Shop o Desire for Extended CLS (NP) o Cost to Generate Repair Data, Later o Available Competitive Support (NP)
Replaced Inventory Value	o Cost to Replace War Reserves o Value of Discarded Inventory
Logistics Interfaces	o Physical Size of Old vs New o Special Handling Required (NP) o Special Transportation (NP) o Availability of Personnel and Equipment, Shared vs Dedicated o Current level of use of Interfaces
Supply Competitiveness	o Percentage of Standard Parts Used o Use of Propriatary Technology (NP) o Commercial Parts Availability (NP)

BCS Responsibility

The responsibility for performing the BCS process lies both with the Combat Developer and the Materiel Developer.(6) The Combat Developer within the Army is usually located within the appropriate School/Center for that type system, and the Materiel Developer is located at the Major Subordinate Command (MSC). The level of effort required in performance of a BCS effort by these organizations becomes more in depth as the acquisition process proceeds. The need to perform LSA Task 203, the major BCS instigator, governs the designation of responsibility. This Task noteably in no way assumes that a BCS is not feasible in the early stages and definitly implies that it is an iterative updating process.

During the Pre-concept and Concept Exploration Phases, the Combat Developer has the priimary responsibility for the BCS effort and most analysis is usually cursory in nature. The Combat Developer should examine and identify the global aspects of logistics support and develop the framework for the support concept. Parameter selection and intial presumption of logistics values should be made.

During the Demonstration and Validation Phases the Materiel Developer takes over the BCS updating effort, not the initial development effort. If any computer modeling was performed in earlier stages, it should now be revised, updated, and expanded. If no modeling had previously been performed, it needs to be started now. Many logistics models are available and cateloged.(7) Modeling efforts prove most beneficial in regards to sensitivity analysis, but are usually cumbersome to set up. Sensitivity analysis allows the analyst to evaluate questionable parameters, the impact of performance on logistics and avoid missing non-obvious problem areas. If BCS analysis or development is left until the design is fixed, then their isn't an inexpensive way to support a design versus logistics support tradeoff problem when found.

The analysis need for Task 203 is sometimes disquised under the shadows of Task 303. Even though Task 303 is usually contracted out. This is a problem since the information needed to do the BCS analysis is 80-90% government provided and the contractor winds up charging the government to provide them information.

The BCS may also, as stated previously, is required by the RAM Rational Report (RRR) process.(3) Care should be taken not to waist analysis time with duplicate activities, LSA versus RRR. This is a problem with systems analysis requirementsbeing of similar function, but covered under different regulatory requirements and needs future added investigation.

Summary

The mounting problems of lack of funds to support systems and the O&S Cost escalations within DOD are a direct result of this lack of attention to logistics impact in system development. Logistics parameters have become the default of performance drivers. The Combat Developer must initiate stoppage of this attitude by addressing logistics in the BCS early on and the Materiel Developer must follow through with in depth analysis before the design is fixed and its too late. Data are available to develop a good BCS in most cases, but excuses are presently prevailing. Analysis techniques are available but are not used or are contracted out inappropriately. The regulatory requirements are their, but proper implementation is short-suited. All in all the BCS process should be more attentive to logistics with more up front activity or the systems of the future will follow the O&S cost pattern of the past.

References:

(1) DOD Directive 5000.39, Acquisition and Management if Integrated Logistics Support for Systems and Equipment.

(2) Mil-Std-1388-1A, Logistics Support Analysis, 11 April 1983.

(3) TRADOC/AMC Pamphlet 70-11, RAM Rational Report Handbook, 1 Jul 1987.

(4) Army Regulation 702-3, Army Materiel Systems Reliability, Availibility and Maintainability.

(5) Logistics Support Analysis Modeling Course Book, published by US Army Management Engineering College.

(6) AMC Pamphlet 700-22, Logistic Support Analysis Primer, Jul 1986.

(7) AMC/TRADOC Pamphlet 700-4, Logistics Support Analysis Techniques Guide, 31 Mar 1986.

BIOGRAPHICAL SKETCH OF AUTHOR

Mr. Jim Wasson received his bachelor of science degree from SUNY at Fredonia, New York and has done post graduate work in both mathematics and operations research/systems analysis. He is a Certified Professional Logistician(C.P.L.) and has fifteen years of government experience in logistics, including equipment maintenance, operational testing, system acquisition and program management. His last two positions were teaching RAM and Logistics Modeling at the US Army Management and Engineering College (AMEC) and currently as the Chief of the Logistics Analysis and Automation Division within the Missile Logistics Center, US Army Missile Command, Redstone Arsenal, Alabama.

Nonsteady State Forecasting of Manpower, Personnel, Training and Facilities Requirements to Support a Weapon System

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ABSTRACT: This article goes into the details of applying automated forecasts to assess the logistics supportability of alternative design concepts. Military applications of the logistics model known as the Personnel Requirements Analysis Model (PRAMOD) are discussed. PRAMOD was designed seven years ago by the author, but received little attention until recent times, because of the Army's institutionalization of the Manpower Personnel Integration (MANPRINT) Program, which requires that alternative design concepts be analyzed for their impacts on manpower and training in the preconcept phase. One of the main goals of the MANPRINT Program is to ensure equal consideration of logistics factors with performance and design factors. The objective of the article is to give the reader some insight into how and where design/logistics tradeoff issues occur. Naturally, Government and contractor organizations obligated to address MANPRINT issues will find the article extremely informative and potentially applicable to their programs.

The article mainly addresses quantitative aspects of MANPRINT analysis, recognizing that the human factors engineering aspects of MANPRINT requires a totally different approach and should be the subject of another article. The newly devised interactive version of PRAMOD used to accomplish the forecasts has the unique capability of permitting nonsteady state analysis. The author explains why this capability is absolutely essential, if one is to have a meaningful analysis. Another unique feature of the PRAMOD is that it permits automatic data storage and retrieval. This last capability makes it possible to obtain a complete quantitative assessment of relevant costs and required manpower within minutes. Finally, the author discusses potential applications of nonsteady state analysis to planning and budgeting of resources optimally.

INTRODUCTION: Automated models exist for approximating steady state manpower, personnel, training (MPT), and facilities impacts due to fielding a new military system. The PRAMOD is the only logistics model known with the capability of doing nonsteady MPT and facilities projections, based on a changing fleet size. A new system is rarely ever completely deployed in one production year. Normally, a new system follows a deployment schedule which may cover a number of years. Hence, the total number of fielded systems in any time period varies. To add to the complication, when a fleet becomes obsolete the fleet will normally be discarded at a nonsteady state rate covering a number of years. Because of this situation steady state models give no measure of the actual impact of fleet deployment and withdrawal on MPT and facilities. As a planning tool a steady state predictor is virtually useless. Some fleets will become obsolete before any meaningful steady state ever occurs. This is particularly true in electronics and other fast moving areas of technology. Needless to say, military systems are tied to the fast moving technologies and therefore especially require nonsteady state analysis.

A logistician planning the fielding of a new system should be concerned about peak demand periods. For example, if a new system requires a type of training program not previously in existence, then a peak demand for the new equipment training occurs shortly after fielding because no one is yet trained. After the initial peak demand, training levels off to steady state demand due to attrition. Training and training facilities should be planned based on nonsteady state analysis to ensure employing resources optimally. To illustrate the nonsteady state nature of the PRAMOD outputs, the next table A giving nonsteady state expected student enrolments and faculty requirements is included. The table identifies the peak demand year.

The PRAMOD was created to solve the difficult problem of projecting MPT and facilities requirements based on a nonsteady state fleet size over time. Since the PRAMOD was initially created in the early eighties, the model has been applied to two military systems with outstanding results. The model has been made available to contractor and Government users through the Army Materiel Command Pamphlet 700-4 known as the Logistics Support Analysis Techiques guide. The LSA Techniques Guide is available through its proponents at the AMC Materiel Readiness Support Activity currently located in Lexington, KY. It is hoped that this article will encourage usage of this unique resource, as well as give a measure of understanding of how it may be applied in doing nonsteady state front-end Hardware Manpower (HARDMAN) analysis for military systems.

BASIC PIPELINE EQUATION: The technique used in developing PRAMOD was to first formulate one pipeline equation tying all critical logistics variables together according to their logical quantitative relationships. Because of the number and complexity of interrelationships between logistics variables, no other strategy could hope to bring together all pertinent elements coherently. The piecemeal approach of relating two and three variables at a time without relating them to the whole logistics structure, as done in several other models attempting to predict MPT impacts, exemplifies the limitations of any approach that is not holistic in spirit. The piecemeal approach not only fails to make true quantitative relationships for the whole logistics support structure but also makes it impossible to do nonsteady state analysis.

Several weeks were required to formulate the pipeline equation describing the nested interelationships between the many variables. The next list contains the logistics variables related by the main pipeline equation for any specified time unit, such as one year. It should be apparent why several weeks were required to develop the mathematical model on scanning this list.

VARIABLE LIST

VARIABLE	DESCRIPTION
P	Fielded or removed number of systems for the year. P is positive if systems are added and negative, otherwise.
R(i)	Total number of personnel needed in the i th Military Occupational Specialty (MOS) per year per system. This quantity may be obtained from the Table of Organization and equipment (TOE), if one exists. Otherwise, it must be approximated based on similar systems. The maintenance personnel Annual Maintenance Manhours from the Qualitative and Quantitative Personnel Requirements Information (QQPRI) document may be employed to develop appropriate values for R(i). The R(i)s are termed TOE numbers because of their connection to the TOE.
A(i)	Composite yearly attrition rate in the i th MOS. A(i) encompasses attrition due to both End of Active Service (EAS) and Non EAS, such as training flunkout, death, AWOL, and so forth. If a(j) for j=1 to Q(i) are attrition rates for each possible way of attritting from the i th MOS, then

TABLE A

USMC LAW PERS	ALS 81 (MACRO)	1F

SUPPORT PERSONNEL & STUDENT BODY COUNT	03-25-82

YEAR	ENROL-MENT	INSTRUCTORS	ASSISTANT INSTRUCTORS	SECRETARIES	ADMIN OFFICERS	1 ST LINE SUPERVISORS	2 ND LINE SUPERVISORS	MISC OTHERS	STAFF TOTAL
1984	62	2	3	1	1	1	1	0	9
1985	121	3	4	2	2	1	1	0	13
1986	173	4	6	2	2	2	1	0	17
1987	220	4	8	2	2	2	1	0	19
1988	342	7	13	3	3	3	1	0	30
1989	244	5	10	2	2	2	1	0	22
1990	155	4	6	2	2	2	1	0	17

the next formula may be employed for finding the composite attrition for the i th MOS.

$$(1) \quad A(i) = 1 - \prod_{j=1}^{Q(i)} (1-a(j))$$

REPL(i) Total number of replacements required in the i th MOS per year.

C(i,j) Class size for the j th training course of the i th MOS per year.

L(i,j) Length in weeks for the j th training course of the i th MOS per year.

N(i,j) Number of instructors needed for the j th course of the i th MOS per year.

K(i,j) Number of classes in the j th course of the i th MOS.

B(i,j) Yearly attrition rate for instructors of the j th course of the i th MOS.

T(i,j) Total number of instructors required to support procurement P for the j th course of the i th MOS.

T(i) Total number of instructors for the i th MOS.

PR(i) Total personnel required in the i th MOS.

DTOT(i) Yearly personnel replacements in the i th MOS.

W(i,j) Average number of weeks in a year that a full time instructor can spend in class teaching the j th course of the i th MOS.

M(i) Number of courses required to train the i th MOS.

DTOT Total of yearly personnel replacements required for all MOSs.

N Total number of MOSs.

N(i) Number of training courses required to train the i th MOS.

Y Average number of work hours per year per worker.

Y(i) Average number of direct productive work hours per year in the i th MOS.

P(i) Productivity factor for the i th MOS. This variable gives the fraction of time that hands-on productive work is being accomplished. In mechanical MOSs this portion of the work day is often referred to as 'wrench time'. Breaks, administrative paperwork, sick time, and other non productive requirements are taken into account by the productivity factor.

A Average yearly usage of the system in appropriately chosen units.

H(i,k) Average number of hours required of the i th maintenance MOS to repair/replace the k th component.

F(i,k) Mean usage between failure of the k th component maintained by a mechanic in the i th MOS.

C(i) Total number of major components maintained by the i th maintenance MOS.

M Average total maintenance hours per system per year.

M(i,k) Average total hours per year per vehicle required for maintaining the k th component of the i th maintenance MOS.

MTOT Total of all maintenance personnel replacements.

DGTOT Grand total of all yearly personnel replacements.

The foregoing list of variables defines all symbols used in the derivation of the basic logistics pipeline equation. All listed independent variables appearing in the pipeline equation are to be regarded as fundamental input to the computer model PRAMOD designed to simulate the behavioral relationships inherent in the pipeline equation. For example, T(i,j) does not appear in the pipeline equation and is therefore not an input to PRAMOD. Such variables are implicit in the pipeline equations, because they may be calculated from the basic input variables appearing in the pipeline equation. Total number of instructors needed to support training T(i,j) is an example of a variable which is calculable employing the basic input variables like attrition rate, procurement/deployment quantity, TOE numbers, course length, maximum allowable class size and so forth.

The next equation gives the form of the pipeline equation for calculating new personnel replacements when TOE requirements are known or easily calculated. Generally, included in this category of personnel are drivers, gunners, commanders, supply personnel, and other personnel with mission either not dependent on the number of deployed systems or easily related to it, such as drivers. For example, a minimum of one driver should be allowed for each deployed vehicle, while the number of cooks are normally not determined by the number of deployed systems but roughly by the number of total personnel in the battalion, division, or whatever organization is being analyzed. On the other hand, maintenance personnel MOS's often depend on the reliability, availability and maintainability (RAM) characteristics and component configuration of the system. Therefore, establishing personnel replacements for maintenance personnel requires a slightly more complicated form. The second part of the derivation of the pipeline equation addresses specifically the determination of maintenance personnel replacements based on component RAM characteristics. However, if TOE requirements can easily be determined for maintenance personnel by some other method, such as using TOE requirements for a similar system, then the simplified pipeline equation given next may be applied to all personnel, simplifying computations considerably. Generally, it is recommended that one project TOE numbers for maintenance personnel offline from PRAMOD for new system deployment by employing projected failure rates, productivity factors, and data from a similar system, if one exists. Since only two or three types of maintenance personnel are relevant in most applications of PRAMOD, the computations required can be done with a hand computer in a few minutes.

The simplified form of the pipeline equation based on known TOE requirements is given by DTOT as

$$(2)\quad DTOT=\sum_{i=1}^{N} PR(i)A(i)[1+\sum_{j=1}^{N(i)} B(i,j)L(i,j)N(i,j)/(W(i,j)C(i,j))]\ .$$

In (2) DTOT represents the total number of personnel replacements for a year assuming the TOE requirements for each MOS is available. As just stated, since maintenance personnel replacements are dependent on failure rates, maintainability characteristics and component configuration, a more complex expression for the pipeline equation yielding DTOT is required. The variables in the variable list starting with Y and ending at M(i,k) are the added variables required to formulate the more complex form of the basic pipeline equation.

The complex form of the pipeline equation used to determine yearly requirements for maintenance personnel is given by MTOT as

$$(3)\quad MTOT=$$

$$\sum_{i=1}^{N}[(PAA(i))/(P(i)Y)\sum_{k=1}^{C(i)} (H(i,k)/F(i,k))[1+\sum_{j=1}^{N(i)} B(i,j)L(i,j)/(C(i,j)W(i,j))]]$$

The derivation of the two forms of the basic logistics pipeline equation follows from basic logical quantitative relationships. Only simple algebra 's required in their derivation. Programming nonsteady state MPT and facilities requirements to a deployment schedule is equivalent to programming the pipeline equations. This was no easy task even with the pipeline equation at hand. Without the guidance of the pipeline equation one would have to conclude that properly programming the complex nested network of relationships would be an impossible task. This possibly explains why only the PRAMOD has the unique capability to project the nonsteady state logistics impacts of deploying a new system on MPT and facilities.

If both pipeline equations are employed then total yearly personnel requirements are given as

$$(4)\quad DGTOT=DTOT+MTOT.$$

PRAMOD determines facilities and training devices requirements very flexibly depending on the judgment of the user. For example, one input to PRAMOD is square feet of office space per instructor. For such variables the input quantity might depend on a number of factors, such as Army regulations, location of facilities, budgetary constraints and more. Training facilities and devices are computed directly proportional to deployment quantities as well as square feet allowed for office space per instructor, training devises per student, lavatory facilities per student, and so forth. The next list of variables related to training and training facilities should assist the reader in visualizing the scope and nature of PRAMOD.

TRAINING AND TRAINING FACILITIES INPUT VARIABLE LIST

1. ratio of secretaries to instructors 2. ratio of administrative personnel to instructors, instructor's aides, secretaries and supervisors combined. 3. ratio of first line supervisors to instructors, instructor's aides,

secretaries and admininstrative officers combined. 4. ratio of second line supervisors to instructors, instructor's aides, secretaries and administrative officers. 5. ratio of miscellaneous employees like janitors, security guards, and so forth to whole training staff. 6. average number of weeks per year in classroom teaching per instructor 7. instructors aides per class 8. students per class 8. length of weeks of each class 9. location of training site(s) 10. course description 11. instructor's salary 12. percent of instructor's salary used to compute aide's salary 13. parking square feet allowed per training device 14. percent of total parking area required for ingress and egress 15. cost per square foot for parking lot construction 16. number of training devices per student 17. square feet of office space per instructor 18. square feet of office space per instructor's aide 19. square feet of office space per administrative personnel 20. square feet of office space per secretary 21. square feet of office space per supervisor 22. square feet of office space per trainee and instructional staff member 23. ratio of additional auditorium space forstage, aisles, etc.. 24. square feet per student allowed per classroom 25. square feet per population allowed for personal use (lavatories) 26. total square feet allowed for workshop/laboratory 27. total square feet allowed for storage of supplies 28. ratio of all allowed space for corridors (usually .05) 29. ratio of all allowed space for special equipment 30. square feet of quarters allowed per transient student 31. square feet of quarters allowed per permanent staff (optional) 32. cost per square foot for vocational training facilities construction 33. cost per square foot for transient quarters construction 34. cost for one instructional personnel quarter 35. cost for one permanent first line supervisor's quarters 36. cost for one permanent second line supervisor's quarters 37. salary per secretary, administrative personnel, first line supervisor, second line supervisor, and miscellaneous personnel 38. ratio of total personnel salary costs used to estimate fringe benefit costs 39. cost per square foot to maintain vocational facility 40. cost per square foot to maintain transient quarters.

It is optional whether one projects the cost of facilities when applying PRAMOD. Facilities input data are relatively fixed. Thus, they may be used over and over again for different applications of PRAMOD. It should be understood that the interactive automated data-set-creating capability relieves one of having to enter all of the input data every time PRAMOD is applied. The PRAMOD is designed with built-in data bases, consisting of all of the input data types listed in this article. Once the initial data bases are established, it is only required to update the data as it changes. The updating process is easily accomplished using standard editor capabilities found in all computer operating systems. Interactive global commands make it possible to batch update a common data input like MOS salary, whereever it occurs in the data base. Therefore, updating takes seconds. Since there exists several hundred MOSs in the Army alone, it could take a great effort to establish an initial data base, if one desires to have instant capability for doing PRAMOD Hardware Manpower (HARDMAN) analysis within minutes on any given military system. Naturally, this would be highly advantageous where timeliness is important. The author has opted to simply add MOS data incrementally as needed. Therefore, the author's Army data base only has about 35 MOSs and the USMC data base has about 30, currently. Since PRAMOD permits interactive choice of any one of its multiple built-in MOS data bases, one can have separate data bases for the Navy, Army, Air Force, or any organizational unit desired, making the PRAMOD highly flexible for a wide range of applications. MOS information is available from a number of organizations within the Army TRADOC Command.

PRAMOD APPLICATIONS: PRAMOD has been applied to two military systems by its creator. The first application came as a result of a request by the USMC to perform an HARDMAN analysis on the US Army Light Armored Vehicle (LAV) system, which was to be a joint operation between the Army and the USMC. The status of the program was changed to be a USMC system only several years later. Because the LAV is a tracked vehicle and the USMC had never developed or deployed a tracked combat vehicle prior to the LAV, the US Army Tank Automotive Command was asked to provide an analysis of the MPT, and facilities required to support the LAV. The USMC was interested in determining cost impacts. They were also interested in comparing several alternate MOS structures for supporting the LAV with MPT and facilities. They wished to know whether it would be better to utilize Army MOSs and training facilities or develop their own.

The PRAMOD was developed by the author at the US Army Tank Automotive Command Integrated Logistics Support Office to support this USMC request. The study took place over about a six month period starting in January 1982. Tables III and IV giving the two MOS structures compared are exerpted from the final LAV MPT and Facilities Analysis report dated May 1982. Table I gives a summary of total costs and personnel manyears required by the two alternative structures. One can see from the Table I that the difference between the alternative MOS structures is almost negligible relative to costs and manyears of effort. Practically speaking, other nonquantifiable issues might easily tilt the decision as to which MOS structure to prefer in favor of the more costly one. Still, the study arrived at a very credible conclusion that not much difference existed between the alternatives presented at that time. A check of the LAV Integrated Logistics Support Plan finalized in 1988 reveals that the USMC did in fact create several new USMC MOSs as suggested by the 1982 study. However, the preponderance of MOSs employed were ones that already existed in the USMC's MOS pool. The new MOSs created were an LAV Officer, Gunnery Sergeant, rifleman, driver/gunner, and an automotive system mechanic.

PRAMOD was applied in 1985 to the Army's XM4 Armored Gun System. This application of the model was totally different in spirit from the first one. The main thrust of the effort was to decide whether the XM4 would be best designed with an automatic loader or more conventionally without one. Because of the complications of designing and building an automatic loader, a natural trade-off existed between the additional costs for a crewman loader versus the costs of designing and maintaining an automatic loader. The PRAMOD was employed to find a break even point, where the additional costs of having an automatic loader would be absorbed by the savings of having a three man crew instead of a four man one. Naturally, substantial logistics differences occur between the two alternative designs. Both MOS structure and training requirements were affected by the differences. Specialized automatic loader mechanical training was required under the automatic loader design concept, while additional loaders requiring much less training were required under the conventional design concept. Hardware costs for an automatic loader design were substantially higher than for the simpler conventional design. Many trade-offs were addressed through the power of the PRAMOD nonsteady state analysis. The Table 3 was exerpted from the final study issued by the Battelle Columbus Laboratories in July 1985 comparing the two options.

SUMMARY/CONCLUSIONS: The two applications were discussed to illustrate the diversity in potential application of the PRAMOD. Whenever a design concept impacts MOS structure, a need exists to measure the impact of the concept relative to other design options. Ramifications of designing complex high

TABLE I

Total cost and personnel for FY84-90 and all variants, FY82 constant dollars:

METHODOLOGY	MOS STRUCTURE	TOTAL COST	TOTAL PERSONNEL MANYEARS
MACRO	Alternative 1	$128,147,154	12429
MACRO	Alternative 2	$126,905,440	12287
	Alt 1 difference from Alt 2	+ $1,241,714	+ 142

TABLE III

ALTERNATE 1 MOS STRUCTURE

KEY: LA - Light Armored
C3 - Company Command/Control
AG - Assault Gun
OTHER WEAPONS: AT - Anti-Tank
AD - Air Defense
OTHER NON-WEAPONS: M - Mortar
BnC2-Battalion Command/Control
R - Recovery
L - Logistics

DESCRIPTION / VARIANT	LA	AG	OTHER WEAPONS AT - AD	OTHER NON-WEAPONS
Driver	3535	1811	3535	3535
Gunner	0331	1811	0331	0331
Commander	0311	1811	0311	0311
Weapon Repair	2111	2111	2111	2111
Optic Instrument Repair	2171	2171	2171	2171
Turret Repair	2146	2146	2146	NA
Weapon Tech	2181	2181	2181	2181
Ground Radio Repair	2841	2841	2841	2841
Radio Technician	2861	2861	2861	2861
TMDE TECH (Analysis set)	2871	2871	2871	2871
Organization Automotive Mechanic (2nd Echelon)	3521	3521	3521	3521
Intermediate Automotive Mechanic (3rd & 4th Echelon)	3522	3522	3522	3522
Fuel & Elec Sys Mech	3524	3524	3524	3524
Body Repairer	3513	3513	3513	3513
Welder, Metal Worker	1316	1316	1316	1316

All maintenance level direct maintenance manhour are listed separately per echelon in the MACRO methodology, and the 4th echelon is not used for the Battalion structure comparison.

TABLE IV

ALTERNATE 2 MOS STRUCTURE

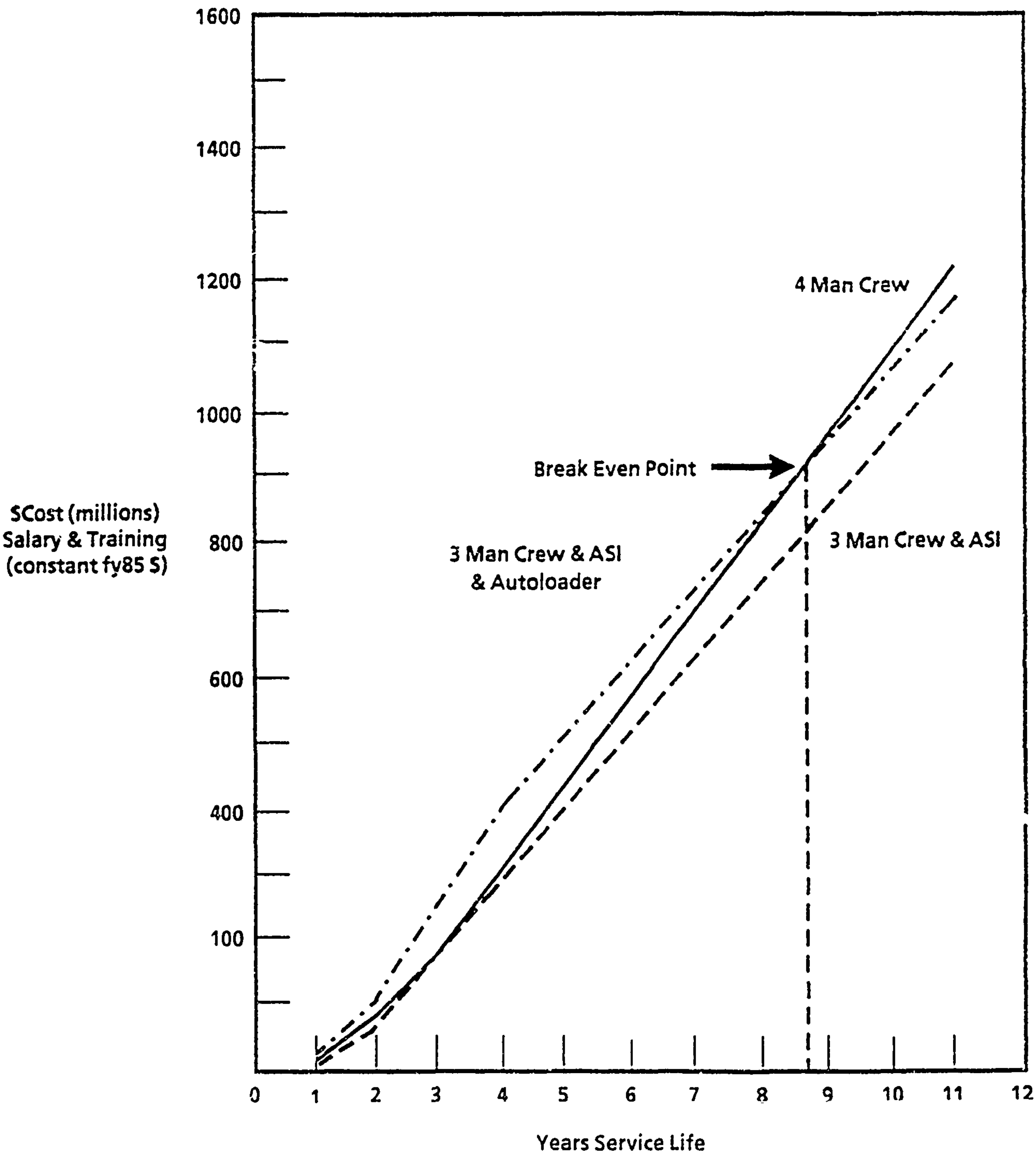
KEY: LA - Light Armored
C3 - Company/Command/Control
AG - Assault Gun
OTHER WEAPONS: AT - Anti-Tank
AD - Air Defense
OTHER NON-WEAPONS: M - Mortar
BnC2-Battalion Command/ Control
R - Recovery
L - Logistics

DESCRIPTION / VARIANT	LA	AG	OTHER WEAPONS AT - AD	OTHER NON-WEAPONS
Driver	18xx	18xx	18xx	18xx
Gunner	18xx	18xx	18xx	18xx
Commander	18xx	18xx	18xx	18xx
Metal Worker, Welder	1316	1316	1316	1316
Body Repairer	3513	3513	3513	3513
LAV Organization and Intermediate Automotive Mechanic (2nd thru 4th Echelon)	35xx	35xx	35xx	35xx
Weapon Repairer	2111	2111	2111	2111
Weapon Technician	2181	2181	2181	2181
LAV Armament - Turret Repairer	21xx	21xx	21xx	*21xx
LAV Fire Control & Optics	217x	217x	217x	217x
Ground Radio Repairer	2841	2841	2841	2841
Radio Technician	2861	2861	2861	2861
TMDE Tech (Analysis Spt)	2871	2871	2871	2871

All maintenance level direct maintenance manhours are listed separately per echelon in the MACRO Methodology, and the 4th echelon is not used in the Battalion Structure Comparison.

*The LAV Armament-Turret Repairer performs 2nd Echelon Fire Control and Optical Instrument.

TABLE 3



$Cost (millions)
Salary & Training
(constant fy85 $)
1600
1400
1200
1000
800
600
400
100
4 Man Crew
Break Even Point
3 Man Crew & ASI
& Autoloader
3 Man Crew & ASI
0
1
2
3
4
5
6
7
8
9
10
11
12
Years Service Life

technology devices into systems should be performed at the early outset of a new program in order to ensure logistics supportability. It is imperative to make the right decisions in the early planning stages, because it will be too late once the system is close to fielding. Early trade-off analysis can enhance the credibility of a new program. Perhaps, it may even save a program from failure and/or lost budgetting. It is a wise move on the part of a new system's program manager to insist on all of the front-end planning that he can get. The application of PRAMOD, as well as other powerful front-end techniques, such as the Army's Logistics Analysis Model (LOGAM), affords methodologies that must not be overlooked in accomplishing this objective. Program managers should be aware of the large number of logistics support analysis techniques available in the AMC Logistics Support Analysis Techniques Guide P-700-4 published and updated periodically through its proponents at the AMC Materiel Readiness Support Activity at Lexington, KY. Logistics models may be located through this guide to assist in performing a wide range of studies in support of the MIL STD 1388-1A. Logistics techniques/models may be found in the guide for life cycle costing, level of repair analysis, useful life studies, quality control, logistics and combat simulations, logistics expert systems, Hardware Manpower analysis (HARDMAN), and many more. This guide should be part of every program manager's arsenal of tools.

With the Army's current emphasis on front-end planning through its MANPRINT, Computer Aided Acquisition Logistics System (CALS), and the Level of Repair Analysis (LORA) Programs, it is believed that usage of automated logistics modeling will become a standard operating procedure and policy for all new systems. The current proliferation and availability of computer technology facilitates doing analytic studies, which would have been impossible fifty years ago. It would be remiss not to take advantage of this great opportunity for optimizing usage of resources and design of supportability into new systems.

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[1] Donald Eldredge and Carolyn B. Davis, "Manpower, Personnel and Training Comparative Analysis for The XM4 Armored Gun System, Battelle Columbus Laboratories, Columbus Ohio, July 1985.

[2] Joseph E. Brierly and George Batcha, "US Marine Corps Light Armored Vehicle (LAV) Manpower, Personnel, and Training Assessment, Volume 1, US Army Tank Automotive Command, Integrated Logistics Support Office, Warren, Michigan, May 1982.

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#160
TITLE: Clothing Exchange of Contaminated Battledress on the AirLand Battlefield (CECBAB)

AUTHORS: Mark H. [illegible]ston, David Chung, and Meyer Kotkin Ph.D.

ORGANIZATION: US [illegible] Materiel Systems Analysis Activity
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AUTOVON: 298-4364

ABSTRACT:

A continuing Combat Service Support Mission Area Deficiency (CSSMAD) in the area of supply and field services has been lack of well-defined requirements for Class II exchange and resupply in a chemical environment. The requirements for Class II exchange and resupply in a chemical environments are particularly demanding. Operations in a chemical environment require large replacement quantities and frequent exchange of some Class II items.

The US Army Training and Doctrine Command sponsored an analysis of clothing exchange requirements in a chemical environment. The study, entitled "Clothing Exchange of Contaminated Battledress on the AirLand Battlefield (CECBAB) (u)", was performed jointly by the US Army Materiel Systems Analysis Activity (AMSAA) and the US Army Quartermaster School. The objectives of the study were to develop alternative techniques for determining Class II clothing exchange requirements in a chemical environment, analyze the combat Class II clothing exchange workload, and determine the best location for conducting clothing exchange operation on the battlefield.

The study team analyzed the different components of Class II demand on the battlefield and developed a LOTUS 1-2-3 macros program that can be used to quantify Class II clothing and individual equipment requirements in a chemical environment in three different theaters: Europe, South West Asia, and North East Asia. The study team also analyzed current war reserve stocks of Class II clothing and individual equipment to determine if current stocks were adequate to meet anticipated demand. Using expertise gained in the Class IX area, the CECBAB study team was able to produce a computerized Class II stockage model that calculates combat ASL stocks at three different echelons. A brief analysis of clothing exchange and bath unit capabilities was conducted.

#139

TITLE: Qualitative Assessment of Battlefield Personnel From the Enhanced Casualty Stratification Model

AUTHOR: Mr. Stephen Sargent

ORGANIZATION: US Army Soldier Support Center
ATTN: ATSG-DDN
Ft. Benjamin Harrison, IN 46216-5700

ABSTRACT:

Modern campaign simulations fail to consider the importance of having the correct mix of personnel skills on the battlefield. For the most part, large computer war games play weapon systems against weapon systems and constrain the performance of the systems only by logistical support, terrain, and environment. When personnel skills are considered in the war fight, startling insights are often revealed. By using a post-processing model to assess the effects of personnel on the war fight, it is generally conceded that although there might be a numerically viable force on the battlefield the force lacks the correct skills to operate the weapon systems available. In analysis, after analysis, we have observed significant percentages of viable major weapon systems standing idle due to a lack of personnel.

The enhanced Casualty Stratification Model became available for the first time in the spring of 1989 and has been well received by the Army's personnel planning community. This paper will examine the enhanced Casualty Stratification Model and how it is able to overlay high resolution personnel play on the output of major theater-level simulations. The paper will discuss the major assumptions of the campaign simulations and how the personnel post-processing model methodology can overcome the campaign's inherent deficiencies. Some graphic examples of the risk of not considering personnel play with reasonable fidelity will be included.

No Paper Provided

#212

TITLE: Systems Analysis of Class I Pre-Position War Reserve Requirements

AUTHOR: Harry J. Kirejczyk

ORGANIZATION: Army Natick R&D Center
Natick, MA 01752

ABSTRACT:

The US Army Natick RD&E Center has initiated project Front End Analysis of Class 1 (Rations) Pre-Positioned War Reserve Material Stocks (PWRMS). The project is jointly sponsored by the Army, Marines, Air Force, and Defense Logistics Agency.

The quantity of rations required to be stockpiled and pre-positioned in various theaters throughout the world to support military personnel in case of war is staggering. For the Army alone this equates to about 70 million rations where one ration represents food for one person for one day. Stockage requirements by theater are a function of many parameters, some of which include: time-phased theater troop strengths; in-theater supply objectives in terms of days of supply due to order/ship/receive lead time, transportation constraints, inter/intra-theater transportation losses, etc. The large stockage requirements translates into a tremendous investment cost and storage space requirement, in addition to associated peacetime rotation problems due to ration shelf life and peacetime consumption rate considerations.

Project objectives are to initially identify all factors, constraints, and policies which impact current stockage requirements and to parametrically evaluate system and ration design parameters relative to their impact on system performance/problem areas. Follow on objectives are to develop and evaluate alternative ration, packaging, supply/rotation, and feeding concepts to reduce current PWRMS requirements and problems while supporting military feeding requirement.

No Paper Provided

#170

TITLE: A Comparison of an Actual Live Firing Exercise to Currently Used Artillery Effectiveness Model Predictions

AUTHOR: Lee Blankenbiller

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

The US Army now has approximately 40 years of experience in the evaluation or analysis of weapon systems. With the advent of the high-speed electronic computer, there exists a huge capability to simulate battles and conduct appropriate analysis of all kinds to study weapon effectiveness, tactics, or other military problems of interest. However, because of the complex, multidisciplined problems inherent in combat modeling, verification and validation of modeling results presents difficult challenges at best. The most simplistic view of the validation process is a determination of whether the model reflects results expected in the real world. The recent introduction of live fire programs within the Army presents the opportunity to gain insights to the accuracy of current analytical models. One such program is the US Army Training and Doctrine Command Soviet Artillery Effects (SAE) project.

The SAE project was initiated by the Department of the Army in November 1987. Through a series of live fire exercises, lethal and nonlethal effects to materiel and personnel from US and Soviet artillery are being examined in detail. A primary impetus of these firings is a comparison of actual damage to predicted damage from selective models used by the Army. With this objective in mind, AMSAA agreed to conduct a computer simulation of the first live fire test and assess the ability of in-house ARTQUIK, CARLETON, and SAMSMAE PK models to predict fractional damage. The results of this experiment indicate that when engagement conditions can be reasonably predicted, and valid input data are available, AMSAA models are more than adequate estimates of predicted outcome.

OPERATIONAL TESTING OF THE C^3I BATTLEFIELD

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INTRODUCTION

The objective of the U.S. Army's Tactical Command and Control System (ATCCS) program is to provide a common suite of nondevelopmental hardware and software to meet its command and control needs at all tactical echelon levels. ATCCS is composed of five programs to develop hardware and software that will provide an operational command and control network stretching from division commanders to the foxhole. The elements of ATCCS support the five Battlefield Functional Areas (BFAs) and comprise what is called the Sigma Star, shown in Fig. 1.

As the U.S. Army moves into the procurement phase of ATCCS, its methodology of performing operational testing must also evolve to keep pace with the added complexity and interoperability. Up to the present, the majority of operational testing of the Army's new fielded systems has taken place in relative isolation utilizing a combination of specialized hardware and manual data collection efforts. As an example, the 1986 testing of the Light Tactical Fire Direction System (LTACFIRE) involved 50-60 personnel and various computer equipment to test a division slice of fire support which represent only a portion of the field artillery fire support elements of ATCCS. Specialized test instrumentation designed specifically for LTACFIRE and its peripheral equipment captured several megabytes of transmitted data during three weeks of typical tactical use. The resulting volumes of data were quite large but represented only a sampling of all the data transmitted. Follow-up analyses required an additional 60 days of manpower-intensive processing to yield conclusive results. While this approach has generally been sufficient for smaller tests, the systems comprising the five points of ATCCS will be highly interconnected and generate an enormous amount of data. One of the communication elements of ATCCS, the Enhanced Position Location and Reporting System (EPLRS), when deployed in the operational configuration at the division level, will consist of two network control stations and up to 400 associated Enhanced PLRS User Units (EPUUs) per network control station. EPLRS utilizes a time division multiplexed algorithm where each time epoch, which is used to transmit position and tactical information, consists of 64 seconds containing 32,768 time slots. Data of interest could occur in any time slot, resulting in a maximum of 1,843,200 records of data per hour which could be required to be captured. Typical operational tests are regularly planned to span up to 14 days of continuous, 24 hour per day operations. No current instrumentation system can handle either the data collection or analysis requirements generated by an operational test of EPLRS. The Forward Area Air Defense System (FAADS), consisting of its suite of defensive weapons, sensor platforms, communication nets, and command and control networks (another example of an ATCCS system) would quickly overwhelm any current instrumentation test system.

In order to meet these testing needs, Applied Research Laboratories, The University of Texas at Austin (ARL:UT), is performing research and development on instrumentation systems and tools for operational testing of the Army Command, Control, Communication, and Intelligence (C^3I) system, especially those systems which comprise the BFAs of the Sigma Star. ARL:UT is currently developing a single instrumentation system to collect and analyze operational data generated by interoperability testing of ATCCS. In addition, capabilities are being designed to allow test officers to view test data being collected in near-realtime and to adjust testing parameters in order to collect the desired data.

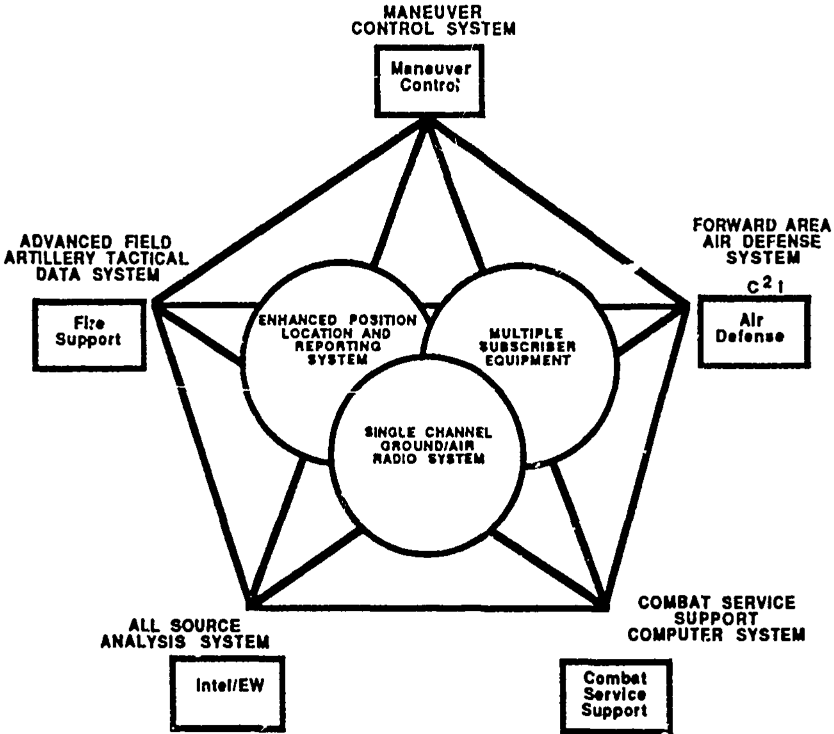

FIGURE 1

ATCCS SIGMA STAR

APPROACHES TO OPERATIONAL TESTING

As newly developed tactical systems grow in complexity, the differences in the types of data collected in operational versus technical testing are beginning to disappear. Due to the growing technical nature of operational testing, many of the same testing requirements and approaches used in technical testing can be adapted for an operational test. However, in addition to the same technical test requirements, operational tests may require the collection of data on a 24-hour-a-day basis for weeks at a time. This requirement of continuous data collection will generate enormous quantities of test data. A basic requirement of any test system will be to successfully collect and store, without loss of data, the information of interest. Not only will these data have to be successfully captured, but the data will have to be stored in a form which will accelerate post-test reduction and processing. Data handled incorrectly could cost additional hours or days of post-test processing time.

In order to successfully capture the data of interest, the test instrumentation must be in a position to collect the data. For wireline communication, this implies that the test instrumentation must be able to tap the communications at the correct communications terminal; for RF communications nets, line of sight must be maintained with the system under test as well as having the correct Communications Security (COMSEC) equipment and crypto keys. These requirements necessitate that the test instrumentation be able to shadow the systems under test for extended periods. A final requirement is that the test instrumentation must not in any way interfere with the normal tactical operations of the systems being tested.

ARL:UT's C^3I INSTRUMENTATION PROGRAM

ARL:UT's role in the development of test equipment to support testing of the Army's C^3I systems began in Fall 1986 with the initialization of a seven year research and development program by Training and Doctrine Command (TRADOC) Combined Arms Test Activity (TCATA), presently the Test and Experimentation Command (TEXCOM). Initial efforts were directed at investigating the current state of instrumentation systems for operational testing which were presently in use at the various Army facilities. In addition, efforts were initiated to perform the following activities:

- Research and understand the Army's C^3I operational test and evaluation requirements

- Develop the concept and specifications for a prototype C^3I Instrumentation system

- Develop and field test the prototype systems

- Develop engineering baseline models for data collection, data merging, reduction and analysis, system simulation, and system stimulation

- Develop the testing methodology for operationally testing the ATCCS

The program was broken down into three major efforts. Phase I consisted of a two year effort to investigate the current state of instrumentation systems presen' n use to gain insight into the methodology being employed, develop the test instrumentation conc. and a prototype system for field demonstration, deploy the prototype to the field, and review field i :ts and system design in light of experience and knowledge gained. Phase II consists of a two and one-half year effort to take the experiences and designs developed in Phase I and develop an engineering baseline capable of collecting and analyzing data from a subset of the systems comprising several points of the ATCCS Sigma Star; develop the capability to stimulate systems under test with precanned scenarios; investigate, design, and develop a small node data collection system which will perform the basic collection activities of the engineering baseline; and perform engineering studies on a large scale data analysis center. Phase III consists of evolving the engineering baseline system to collect data from all systems comprising the Sigma Star; to design and develop a test controller concept and facility to provide realtime test control and direction, and to develop the engineering specifications for a data analysis and control center.

INITIAL EFFORTS

Phase I began in Fall 1986. Since ARL:UT was new to the field of C^3I instrumentation,[1] an effort was begun to gain an understanding of current Army tactical systems to be instrumented. As part of this process, ARL:UT visited various testing activities to evaluate current instrumentation systems. The facilities visited are summarized in Table 1. This effort was to gain knowledge of all test instrumentation presently in use and to determine if any of the systems visited could be used as a baseline concept for future C^3I Instrumentation work. After reviewing several systems in depth, ARL:UT recommended that the current instrumentation system software supporting testing at the Electronic Proving Grounds (EPG), Fort Huachuca, Arizona, be modified to support the initial prototype system for field demonstration. This was considered a lower risk approach than a software cold start.

While the software to support the prototype system was a modification effort, the supporting hardware outside of the computer processor would be based on a totally new design. The computer system would remain based on the system in use at EPG, a Digital Equipment Corporation MicroVAX II with communications processors from SIMPACT Associates providing the primary handshaking and

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[1] ARL:UT is a non-profit organization performing applied research in Department of Defense (DoD) problems. Until the C^3I Instrumentation program was initiated, ARL:UT's expertise mainly lay in the areas of underwater acoustics and naval warfare systems.

TEST ACTIVITY	TEST SYSTEM	SYSTEM TESTED	COMPUTER	OPERATING SYSTEM/ LANGUAGES	INSTR. SHELTERS
FABD FT. SILL, OK	DCMS SOFTWARE SUPPORT CNTR	TACFIRE AFATDS	DEC 11/750 DEC 11/785	VMS FORTRAN BASIC DATATRIEVE, Rdb	40' VAN 30 POWER COMMERCIAL EQUIPMENT
ADABD FT. BLISS, TX	ACSS GOAL POST II DLES	FAADS STINGER TADL-A,B,J AN/TSQ-73	VAX 11/750 GRID PC	VMS MS-DOS FORTRAN	20' VAN S250, 20'VAN COMMERCIAL EQUIPMENT
CEBD FT. GORDON,GA	GPIB BASED INSTRUMENTS	COMMO EQUIPMENT	HP 9836	HP O.S.	OFF-THE-SHELF COMMERCIAL TEST EQUIPMENT
INSBD FT. HUACHUCA, AZ	AI/EWTS EW MONITORING	ALL ELECTRO-MAGNETIC RECEIVERS/ TRANSMITTERS	COMPAC Z-80 HP	MS-DOS FORTRAN, C	40' VAN, UPS STYLE TRUCKS, PORTABLE CASES, COMMER-CIAL & RUGGEDIZED
CDEC FT. LEWIS, WA	PLANNING STAGE	ACCS INTEGRATED TESTING	N/A	N/A	N/A
ARMTE, WHITE SANDS MISSILE RANGE	SIMTRACC WEST-D DLTS, CEM	AN/TSQ-73 HAWK & PATRIOT AIR DEFENSE SYSTEM	POINT SYS VAX 11/750 PDP 11/73 HP 9845	RDOS PMS 2 VMS FORTRAN RT-11 FORTRAN HP O.S. BASIC	40' VAN 40'VAN STEP VAN STEP VAN
EPG FT. HUACHUCA, AZ	TIS, MINI-TIS, MICRO-TIS	TTIDS TADIL-J MCS, TACFIRE AN/TSQ-73, HAWK ASAS, MSE, EPLRS	DEC 11/750 DEC MICRO-VAX GRID	VMS, uVMS MS-DOS FORTRAN PDP-11 ASSEMBLY	40' VANS PORTABLE CASES COMMERCIAL & RUGGEDIZED

TABLE 1

TEST INSTRUMENTATION REVIEWED BY ARL:UT

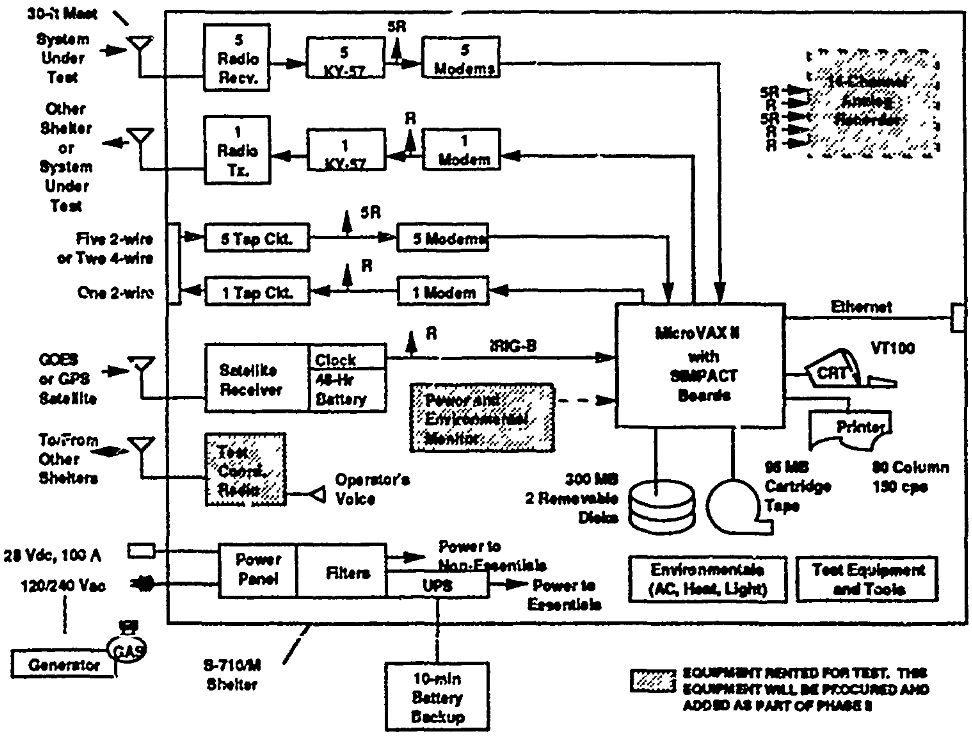

FIGURE 2

INSTRUMENTATION PROTOTYPE

C^3I DATA COLLECTION SYSTEM BLOCK DIAGRAM protocol interfacing. An S-710 tempest-approved shelter developed for the National Security Agency (NSA) would serve as the basic instrumentation enclosure. The shelter would contain five VRC-12 Army radios and associated COMSEC equipment to collect data over RF communication nets, and five modems and tap circuits for wireline taps. The environmental support equipment and associated peripherals to support data collection would also be housed in the enclosure. Shelter power would be provided by a generator set towed behind the system. The system would be required to be totally non-intrusive, self-contained, mobile so as to shadow the systems under test, and able to be airlifted worldwide by C-130 aircraft. Figure 2 is a block diagram of the initial prototype system.

Two data collection systems were required as part of the initial effort. In addition, an infield data reduction and analysis shelter was required to support data analysis during field demonstration. A third S-710 shelter was developed to house a single MicroVAX II computer and workspace to perform data merging and analysis on the collected data. The software development to support this effort was a new start due to different analysis requirements by TEXCOM. All software for both the data collection and the analysis system was written in VAX FORTRAN. The data analysis system utilized the INGRES commercial database for data retrieval and manipulation.

Efforts began in earnest on software modifications and hardware development in September 1987 Initial schedules were to deliver the system for field demonstrations by July 1988, however, the efforts were accelerated such that the systems could be given an infield proof-of-concept test during the III Corps, 2nd Armored Division Brave Shield/Golden Saber Exercise in March-April 1988. Due to the short timeframe involved, only the Maneuver Control System (MCS) would be instrumented.

The systems were completed on schedule and deployed during Golden Saber 88 (Figure 3). One Data Collection System (DCS) was collocated with the Division Tactical Operations Center (DTOC), the other with the Forward DTOC and the Division Artillery (see Figure 4). The data analysis shelter remained parked at West Fort Hood for the entirety of the test.

In all, over four days of test data containing 4026 tactical messages were collected during the exercise. Since Golden Saber was a free play exercise, no ground truth data were available to compare performance levels of the C^3I Instrumentation systems. However, manual data collectors were present during the test and a post-test analysis was performed to compare manual collection efforts with that of the C^3I systems. In a comparison of 24 sets of collected data, the DCS systems collected a larger set of data in all but three cases. In these 21 cases, 75% of the sets contained manually collected data which was a total subset of that collected by the C^3I Instrumentation system. In the other 25%, the manually collected data and that collected by the DCS contain a common intersection of messages.

These discrepancies could be attributed to problems experienced with the incorrectly calibrated VRC-12 radios, several of which had receive sensitivitiy levels set much less than those specified in the performance specification. Problems were also attributed to DCS operator error. Overall, TEXCOM ranked the demonstration test as successful, as it met all test requirements.

Additional post-test Phase I efforts consisted of reviewing all test results, correcting several hardware system and software problems detected during the test, and documenting all software modifications and hardware designs, which were delivered to TEXCOM Headquarters in December 1988.

PRESENT EFFORTS

Phase II efforts, presently underway, are to take the experiences learned from developing and fielding the initial prototypes and to re-engineer the data collection and analysis system. The goal is the development of an engineering baseline model which would support procurement of a suite of instrumentation systems necessary to support Army testing requirements through the mid-1990s.

In addition to data collection capabilities of Phase I, Phase II efforts consist of the development of high level tools for automating the creation of missions and resulting tactical messages for canned simulations. These simulations will be used to provide a stimulation capability to the systems under test, substituting for units and tactical systems not otherwise available. Additionally, stress level testing of

FIGURE 3

C^3I INSTRUMENTATION SYSTEM
DATA COLLECTION SHELTER AND GENERATOR SET

FIGURE 4

BRAVE SHIELD/GOLDEN SABER '88 EXERCISE
C^3I DATA COLLECTION SYSTEM AND GENERATOR SET
DEPLOYED WITH 2nd DIVISION, 142nd SIGNAL BATTALION

systems under test will be implemented. A generic reconfigurable probe interface to systems under test and a small suitcase node capable of the data collection and stimulation operations are also desired during this phase of effort.

Since software development has become the dominant cost in today's systems, a goal for Phase II development is to minimize this cost. The design goal of the small node is to perform all data collection functions in reduced capacity (i.e., number of channels). In order to minimize development efforts across both systems, a maximization of software efforts would be attained by developing one set of software to run on both systems. In addition to minimizing software development costs, considerations were given to maximizing flexibility and expandability by moving to an open computer architecture and standards, and designing the systems with a parallel/distributed processing environment in mind to accommodate later expansion. The current DCS architecture is based on Digital Equipment Corporation's MicroVAX II and is constrained by the following:

- No clear delineation of realtime system responsibilities within a larger, more generic operating system environment.

- The present front-end communications processor residing on the MicroVAX II Q-22 bus is from SIMPACT Associates and is programmable in RSX-11/Assembly language; while the unit performs communication interfacing adequately, it is extremely limited in performance and has a poor software development environment.

- Developed software is heavily dependent upon both the operating system and the hardware. This makes system enhancements both expensive and difficult.

- Digital Equipment Corporation's Virtual Memory System (VMS) operating system is vendor proprietary; a more open environment of a UNIX-based approach is preferred.

- MicroVAX II communication bus is based on Digital's Q-22 16-bit bus. While this is a 16-bit data bus with a 3.3 Mb/s throughput rate, 32-bit buses with throughput rates on the order of 40 Mb/s are now available.

- The present hardware contains insufficient processing power to support added functionality of simulation and stimulation.

In light of these restrictions and the desire to be software compatible between the data collection shelters and the small data collection node, ARL.UT investigated the possibility of basing all realtime functions in an embedded system running a realtime kernel. Several commercial off-the-shelf processor boards have been investigated and identified which support the development of both the small node and the data collection shelters under a realtime kernel environment.

Current plans are to write the realtime embedded applications software in Ada and C. These functions would perform operations of data capture, protocol support, stimulation, simulation, and data collection timestamping. It is planned to base this configuration on a Versamodule Europe (VME) bus. The VME bus has been determined to be the most cost efficient, technically sound replacement for the Q-bus configuration. Advantages of a VME bus configuration include support for both ADA and C, development environments on a variety of commercial workstations, non-proprietary operating system; also the VME bus will integrate directly into FUTUREBUS which should contain even greater execution speed (400 MB/s), fault tolerance, and ruggedness. In support of software development, several realtime development systems are currently available which provide a versatile and powerful software development environment for embedded systems. Of those commercially available, Ready Systems VRTX 32 and Wind River Systems Vx Works have been identified as the two most promising candidates.

While all realtime functions will be based on a realtime embedded system, all non-realtime functions and third party workstation software, including commercial databases and graphics packages, will be run on a ruggedized MicroVAX or SUN workstation. This approach would maintain the flexibility of applying the latest commercial products while at the same time keeping all realtime functions confined to minimum operating system changes. The small node software will contain all realtime applications software and a limited user interface. Using this approach, only one set of applications software will need to be developed, maintained, and kept under configuration control. Figure 5 shows the Phase II software architecture.

Hardware upgrades currently underway on the data collection shelters include replacing the non programmable modems with Tactical Communications (TACCOM) programmable modems, installation of VHS analog recorders to record all preprocessed data, upgrade of current Army VRC-12 radios to the new Single Channel Ground/Air Radio System (SINCGARS) radios, addition of power and environmental monitors, and the addition of the new realtime processor and graphics workstation to enhance the operator interface.

The small node will have the same data collection and stimulation capabilities of the data collection shelter but on a limited basis. Only four channels of data will be available in the small node as compared to up to 16 channels available in the data collection system. The small node will have the ability to collect data in a variety of situations not possible with the larger data collection systems such as in tactical vehicles or aircraft. As such, the small node physical requirements are. no larger than briefcase size, weight less than 40 lb, power consumption less than 200 W, temperature tolerance greater than 50°C, and ruggedized to withstand vibration, dust, and moisture which would normally be encountered in an operational environment. ARL.UT has investigated several off-the-shelf small node packages currently available but has not been able to find a package to meet these requirements and also be compatible with the software development environment described above. As such, work is currently proceeding to develop an engineering prototype of the small node.

Phase II development efforts are proceeding as scheduled. Top level software designs are being developed utilizing the abovementioned software development environments to collect, stimulate, and analyze data from the FAADS, EPLRS, MCS, TACFIRE, and All Source Analysis System (ASAS) tactical systems. An engineering prototype of the small node is being developed and is scheduled to begin testing late Spring or early Summer 1990.

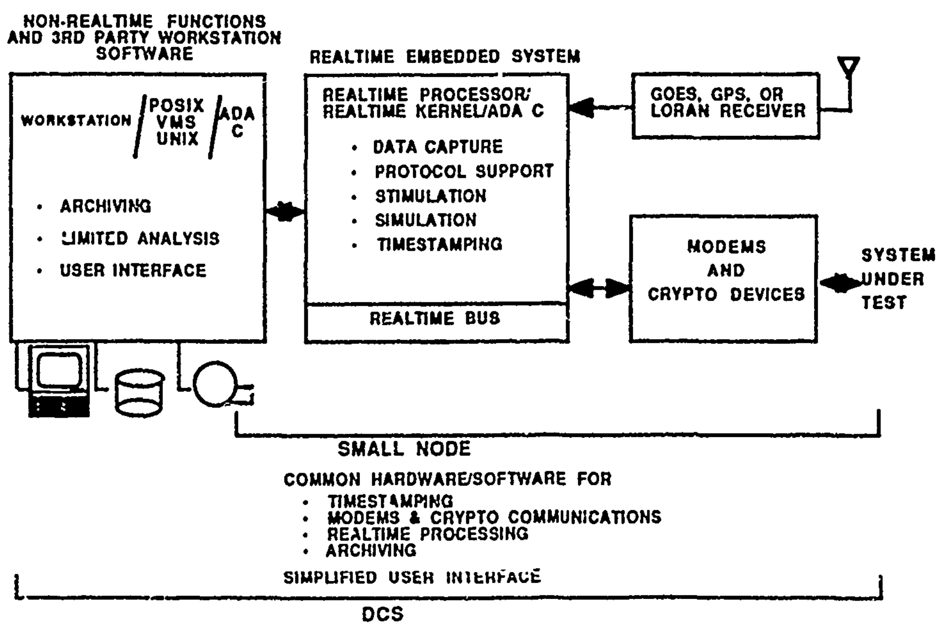

FIGURE 5

PHASE II
DCS ARCHITECTURE

FUTURE WORK

Phase III efforts are to expand the engineering models developed in Phase II to collect and analyze data from and between all points of the Sigma Star, and to develop a realtime test controller. This test controller will provide the test director in the field with the capability to monitor and control the data being collected, and to compare actual results with those which were projected. This process would be used to alert the test director should any problems develop during the test, and to provide the opportunity to alter the scenario if necessary to bring the test into conformance with the design plan. This would minimize the risk of not having sufficient data to answer test issues.

The basic concept is to have a central control facility which will supply the test director with a global analysis of how the test is proceeding. (see Fig. 6) Since future testing of ATCCS can cover large geographic areas, each DCS will act as a remote node, collecting data from and stimulating systems located in its general geographic vicinity. A merging and reduction of data collected from the DCS will be fed into the analysis function - the results of which will be user outputs to the operators - and to the simulation function which will be used to simulate systems not presently fielded. A knowledge-based test controller's assistant will be developed as an expert system to monitor the data as they are collected. The sufficiencey of the data being collected for meeting the needs established by the test issues will be evaluated, and a test controller warning will be generated if test issues are not being properly addressed by the data being collected. The controller's assistant will suggest a course of action to rectify any abnormality, ensuring that changes to the scenario are realistic and fit into the overall test plan and test issues.

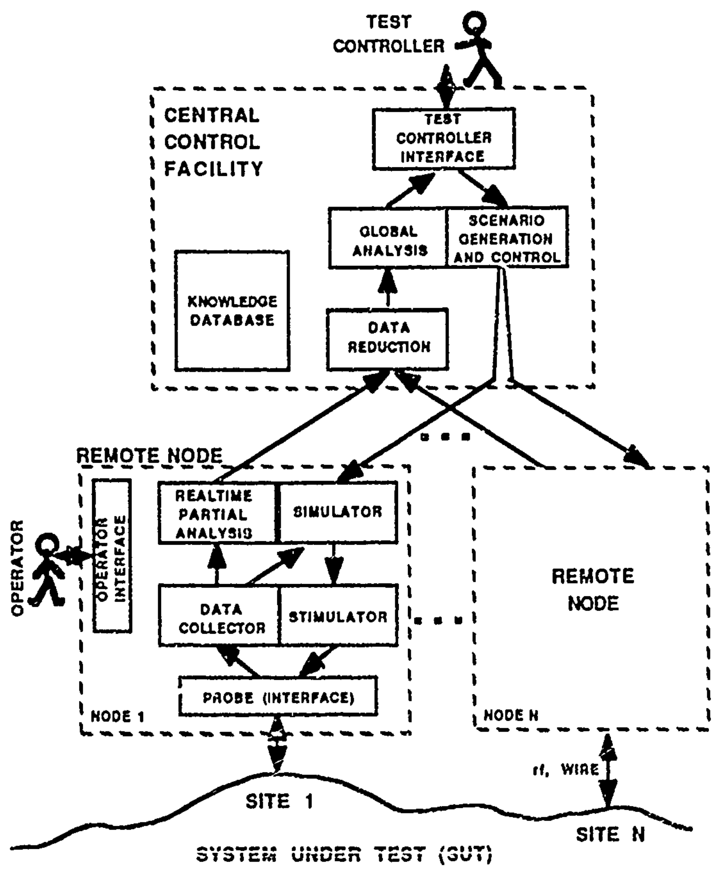

FIGURE 6

PHASE III
SYSTEM CONCEPT

The DCS will perform the data collection, generate a partial analysis to support the simulations involving a smaller tactical area than covered by the central control facility, and generate the appropriate stimulation to interface with the tactical systems under test. On a limited basis, where a test does not necessitate the central control facility, the DCS will act as the test control facility performing the same, but on a reduced scale, functions. No knowledge database or test controller assistant will reside at this level. The small node will, as before, act as a data collector and as a very limited system stimulator on a reduced scale.

Presently, Phase III development is scheduled to begin in FY92 and extend approximately to FY95.

SUMMARY

ARL.UT is developing the hardware and software systems to support testing of the Army's C^3I ATCCS concept scheduled for implementation in the mid-1990s. As concepts of testing change and new tactical systems enter the inventory, the C^3I Instrumentation system being developed will be evolved to successfully provide testing suites for the U.S. Army.

This work has been supported under TRADOC and is under the direction of TEXCOM HQ located at Fort Hood, Texas.

#121
TITLE: The Efficient Use of War Games

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ABSTRACT:

War games provide the cheapest and most convenient means of involving military personnel directly in studies. They offer the advantages over exercises that they are not constrained by real estate or timeframe, and over simulations of increased operational realism. They are, however, not usually suitable for use as the sole or primary analysis tool for specific study topic because they are, in general, not amendable to replication to investigate the effect of varied conditions or system parameters.

The costs involved in creating and maintaining effective war games are often substantial compared to alternative operational analysis (OA) techniques and it is essential to ensure that the data generated are used in the most efficient manner.

The paper describes the use of the RARDE Divisional War Game (DWG) which represents the majority of the assets of 1(BR) Corps and of the first operational echelon of the threat forces. In order to ensure that the DWG contributes as widely as possible to UK Land Systems OA studies, emphasis is placed on the recording of game events and decisions in a relational database which permits the rapid extraction of battle statistics and other data. A range of complementary analysis techniques have been developed and a number of examples are described.

The DWG Replay which enables a scenario to be replicated with a reduced number of players in order to examine a specific system in detail.

Functional capability models which address a single aspect of the Land/Air Battle (e.g. indirect fire, ammunition supply) and use the DWG to provide the basic scenarios.

A number of recent examples of studies in which these techniques have been applied are given.

PAPER IS CLASSIFIED
REQUESTS FOR INFORMATION SHOULD
BE DIRECTED TO ORIGINATING AGENCY

#172
TITLE: TOW Accuracy Study

AUTHOR: David S. Barnhart

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5017

ABSTRACT:

The gunnery of TOW gunners has come under serious review in the last two years. The problem of less than anticipated TOW accuracy at NTC Rotations was initially blamed on the TOW-MILES training system which is used by all units firing live fire at NTC since cost prohibits firing live TOWs. However, an investigation by the US Army Infantry School, which included firing close to 200 live TOWs with 2 1988 NTC rotations, established that live TOW and TOW-MILES perform statistically about the same at Ft. Irwin. Therefore, Department of the Army (SARDA and DCSOPS) have directed a TOW Accuracy Study which includes three study plans examining historical data and evaluating TOW tracking from various sources and two live fire test phases utilizing the unit gunners from a scheduled NTC rotation. AMSAA is the coordinating agency for the study and is concentrating on isolating the factors that affect TOW gunnery and delineating which problems can be addressed through hardware improvement or modification and which problems can be isolated to training. This paper describes the study progress to date and the plans for completion of the task.

Paper is Classified
Contact Originating Agency for Questions

#169

TITLE: Analyses of Attack Angle Distributions and Engagement Ranges of Combat Vehicle-Combat Performance Operational Assessment Data Base

AUTHOR: W. Donald Johnson

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

This paper is a study of the Bradley Combat Vehicle - Combat Performance Operational Assessment data base which was developed by the US Army Operational Test and Evaluation Agency during battalion-sized force-on-force testing conducted at Ft. Hood, TX in May 1987. The RED and BLUE battalion-sized elements consisted of a mix of main battle tanks and infantry fighting vehicles. The analysis in this paper concentrates mainly on the data pertaining to the BLUE M1 and RED T80 surrogate (actually M1) main battle tanks.

Statistical analysis of attack angle distributions over a variety of engagement conditions such as firer movement, target movement, battle scenario, and weapon type is performed. An aggregated attack angle distribution for the long-range anti-tank class of weapons is developed. A comparison of attack angles against infantry fighting vehicles is shown in an attempt to develop an overall attack angle distribution for both vehicle types.

Engagement ranges of tank-fired weapons, ATGMs, 25/30mm, and RPGs is examined. Average range of engagement and distribution of engagement ranges is developed for the various weapon classes.

Improving the Efficiency of Test & Evaluation With Sensitive Measures of Effectiveness (MOE)

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ABSTRACT

Efficient, valid test and evaluation of manned systems requires an efficient method of identifying:

- Critical mission tasks,
- Potentially critical mission tasks,
- Conditions under which those tasks become critical,
- Performance data required to assess the elements of critical task performance contributing to mission effectiveness,
- Information management methods required to evaluate system/unit effectiveness from the test data, and
- Sensitivity analysis functions to determine optimization of task performance relative to system/unit effectiveness.

While each task performed during a mission is expected to contribute to some degree to the level of mission effectiveness achieved by a unit, different tasks will have differential impacts on the mission effectiveness. Even the same task performed at the same level but at different times during the mission may have dramatically different impacts on mission effectiveness. If the impacts of the performance of all mission tasks on mission effectiveness are accurately known and correlations among task performances are known, a unit's mission effectiveness can be assessed. This is possible even though the unit performs only a portion of the mission.

Reliable system test and evaluation can be performed by identifying critical tasks and focusing testing design and data collection and measurement on those critical tasks. In addition to selection of critical tasks, knowledge of the task performance impacts permits assessment of task performances in terms of the factors used to assess mission effectiveness — task performances are assessed only with regard to their relevance to mission effectiveness.

The relationship between task performance and mission effectiveness constitutes a task/mission effectiveness model. The model lets us "see" many relationships not clearly visible without it. Some of the relationships which must be known to design efficient manned system tests, and to efficiently collect and process data are as follows:

- Performance variations of a given task may not be linearly related to mission effectiveness.
- Couplings among tasks may result in critical task interactions impacting mission effectiveness.
- Mission conditions may influence the relationship of task performance to mission effectiveness.

All of these relationships can be determined analytically from a task/mission effectiveness model.

This paper describes the theoretical basis for the Task/Mission Effectiveness Model, sources of data for developing the model, its uses in test and evaluation, and application data.

IDENTIFICATION AND SIGNIFICANCE OF THE OPPORTUNITY

"ARMY 21" postulates a modernized force designed to fight and win two low to middle intensity wars simultaneously. The force must be fashioned also to fight and win a single high intensity war in a nuclear environment while sustaining a low intensity conflict in another region of the world.

The doctrinal concept employed to meet this mission incorporates active and reserve forces using technologically sophisticated weapon systems and high speed, secure, intelligent communications equipment. The Airland Battle doctrine embraced by the Army necessitates effective command and control (C^2) to orchestrate the extremely active battlefield with deeper and wider areas of operation using a multiplicity of operating and support systems to employ an effective fighting force.

The Army modernization program has focused over the past decade on acquiring hardware systems to improve force capability. While considerable effort has been directed toward human issues, only recently has the Army acknowledged the importance of man–machine interface in measuring total system performance.

System Effectiveness

System effectiveness may be described as the interaction of all elements of the system engaged harmoniously to achieve an objective state. The "battle system" is not unlike others in that it also is an interdependent group of elements forming a unified whole. Framed in a combat environment, the commander, the staff, the soldier interact with their equipment and organizations to form a "battle system" to achieve an objective state.

System effectiveness for hardware items or weapon systems is traditionally cast in familiar terms like supportability, lethality, sustainability, availability, mobility and so forth. Requirements documents specify parameters by which these weapon systems may be expected to interact within the "battle system" contributing to a desired state. Rate of fire, speed, mean time between failure, rate of consumption, and others are typical categories of measures applied to evaluate the effectiveness of a particular weapon system in operational conditions. System specifications serve to describe the expected performance of a particular item in objective, quantitative terms.

Hardware Approach

The introduction of new weapon, communication, and training systems into the "battle system" is evaluated almost exclusively by the objective specifications of the inserted technology. The U.S. Army Research Institute (ARI) recognizes that the command group, the commander and staff, are typically evaluated based upon functional task allocation and accomplishment. Expected outcome of a C^2 task is described and command group performance is measured against the success or degree of failure at the end of an event.

Although ARI has developed and tested various methods to establish performance measures to quantify command group effectiveness, no methodology is available to demonstrate the impact of technology insertion on system effectiveness when considering C^2 as a critical element of the system. To provide reliable indicators of total system performance, the need exists to develop a method to quantify the decision process as it interacts with the newly inserted system.

Total System Performance

User testing is the responsibility of the U.S Army Operational Test and Evaluation Agency and the U.S Army Training and Doctrine Command. New system user testing produces data on operational effectiveness, suitability, and soldier–machine interface, with the primary focus on system performance. The most desirable output of user testing is the verification of doctrinal concepts, organization, operating techniques, training, and support. These critical evaluation elements are directly associated with and impact upon C^2 functions.

The fundamental issue this research effort addresses is the feasibility of developing a method to determine the performance impact on C^2 effectiveness when new "weapon" systems are introduced to the "battle system". The initial research and development approach described here focuses on quantifying the impact of command group performance on unit effectiveness given a particular technology insertion, for example, the Multiple Subscriber Equipment (MSE) communication system.

TECHNICAL OBJECTIVES OF THE RESEARCH

Assessment of command group performance involves two steps: 1, defining the summary Measure of Effectiveness (MOE), and 2, identifying the command tasks and determining how the quality of command task performance impacts the unit's mission effectiveness.

Defining the summary MOE requires building a model of authorities' effectiveness preference which is acceptable to many investigators and military authorities. While definition of mission effectiveness is a necessary tool to support user testing and a summary MOE will be used in the research, research on methods of summary MOE synthesis is not the central issue here.

The central issue of research to support user testing is determining the impact of command task performance on mission effectiveness. If we could know how task performance impacts on mission effectiveness we would know how to assess performance of the tasks as they are executed. Further, we would know what information to collect, when to collect it (i.e, the specific mission situations in which to collect data), and how to process the data to assess task performance. However, assessing task performance is complex, since task performance can impact mission effectiveness both directly (by changing values of factors used directly in the MOE) and indirectly (by influencing, perhaps limiting, the performance of other tasks). That coupling with other tasks causes difficulty in assessing the value of any single task performance to mission effectiveness.

The impact of the performance of command tasks on mission effectiveness is apparently a complex relationship, but it is a relationship we must understand to specify and design C^2 equipments, train command staffs, and efficiently test systems. A further complication is that the complex relationship between command task performance and unit effectiveness may change with variations in mission type, unit configuration, environmental conditions, level of command, and enemy force make-up. Thus, there is a need for an efficient method for formulating that relationship and adapting it to the requirements of each particular C^2 situation.

A promising approach to efficiently formulating that relationship is the adaptation of a theorem from optimal control theory. Optimal control theory deals with determining the sequence of control levels (analogous to command task outputs) for a system which will result in optimizing the value of a selected objective (goal) function (analogous to a summary MOE). To accomplish that control synthesis, the optimal control synthesis method uses an efficient method for evaluating all possible alternative combinations of control levels without actually constructing all those combinations. It is never possible to actually form and compare all combinations and then assess their impact, but a theory has been developed which accomplishes the same result in a practical and efficient way.

When optimal control theory is used to synthesize automatic controls, the equations describing the dynamics of the processes and the factors limiting performance must be explicitly known. However, when the system includes human operators whose responses significantly govern the quality of performance, as is the case with a C^2 system, the system dynamics and factors limiting performance are not completely known. We have extended the theory to applications where the dynamics and factors are not explicitly known but are known to be embedded in demonstrations (or certain types of simulations) of superior performance.

The methodology has been applied with good results to assessment of pilot flying performance (Connelly, 1983) and to Army teams operating tactical data processing equipment (Connelly, 1981). While assessment of aircraft flying performance is a good demonstration of the method, because it deals with a single operator and dynamics of a single vehicle and thus is considerably different from assessment of C^2 effectiveness. The tactical data processing application is more like that of C^2 systems with several important differences. One difference is that the command tasks employed were standardized, a set of simple cognitive, motor, and communication tasks. Also, the summary MOE was very simple, time to complete the mission. This simplified the assessment of command task effectiveness. Finally, the mission considered did not include the broad dynamics of maneuvering forces and environmental factors common to C^2 systems.

Recognizing these differences, the application does permit the pre-calculation of a measure for assessing the impact of each task performance on the mission effectiveness. The pre-calculation is complex, but the on-line application of the method to assess each task performance is simple. This methodology is being extended to develop user testing measures for C^2 systems. The method should be especially useful for assessing a new or modified C^2 system which impacts some, but not all, of the C^2 tasks. By focusing testing on performance of those tasks affected, performance of other C^2 tasks need not be tested.

Overview of the Method

The Maximum Principle (Elgerd, 1967) is an optimal control theorem which when extended and applied to systems with human operators states that in order to assess the performance of a task by assessing its total (direct and indirect) impact on summary mission effectiveness, the resources expended to perform the task must be compared to the achievements accomplished by that task performance. A reference for that comparison can be pre-computed to structure and simplify data collection during performances. This provides a convenient, easy-to-use assessment tool which can be used to plan data collection by indicating the variables to observe during a mission, and specifying levels of the variables to detect. It also provides a predetermined formula which accepts the data and computes the task performance and mission effectiveness assessments.

Understanding application of the theory requires an introduction of the concept of state and state variables to the command and control process. Assessment of tasks which are performed in a dynamic environment must be accomplished by considering the change in the state of the situation when the task is performed. The state change may be due to the task performance or may have occurred during the task performance but not have been caused by it. For instance, collection of information changes the state of information from one level to another – as represented by a change in the value(s) of the information state variable(s). (Note: more than one state variable may be used to represent the condition of a factor such as an information factor.) Analysis of information changes the analysis state variable(s) from one value to another. Development of a plan changes the plan development state from one value to another. Developing and issuing orders changes the order state from one value to another. Further, carrying out orders to move, to locate the enemy, to fire on the enemy, and to report the contact will each change at least one mission state varible from one value to another.

Some state changes can be complex. For instance, firing on the enemy may neutralize a portion of the enemy force but also alerts the enemy and reveals friendly firing positions.

While a task is being performed, state changes not directly influenced by the task performance can occur. The environmental conditions can change state. Equipment can fail and thereby change state. Even doing nothing can result in a state change: intelligence data gets old and out of date, or plans are no longer appropriate, or the enemy has changed positions, strength, disposition, etc.

Assessment of a task performance according to its impact on unit effectiveness employs a Moment-to-Moment (MTM) measure. The MTM measure, adapted from optimal control theory, consists of a function of the state variables. The MTM measure is related to the summary MOE which accumulates performance scores during the mission. For ease of explanation it is assumed that the selected MOE is a penalty measure — a value to be minimized, such as time to achieve an objective. The measure can also be formulated as a value to be maximized. Also for ease of explanation the MOE is assumed to measure the resources used to accomplish the mission. The MOE actually measures whatever factors are specified in the summary MOE.

With the assumption just stated, the MOE is thought of as measuring the accumulation of resources used during the mission. In contrast, the MTM measure uses a function which is the expected additional resources (EAR) required to complete the mission from the present state. For instance, at the beginning of the mission the value of MOE is zero, because no resources have been used. At that time, the value of EAR equals the expected final value of MOE, because the expected final value of MOE is the expected resources required to complete the mission. As the mission progresses, the value of MOE increases as resources are used and the value of EAR decreases as the expected additional resources required to complete the mission decrease. In fact, if the total battle group is performing as expected on task j then,

$$MOE_j + EAR_j \text{ (state variables)} = MTMj = 0.$$

This equation states that as resources are used and accumulated by the MOE, there is a corresponding decrease in the additional resources required, keeping the MTM equal to zero. As the task is performed, the resources used are measured by the MOE, while the task accomplishments in the mission environment are represented by the state change measured by the EAR function.

But suppose that resources are used during a task performance (causing an increase in the MOE), but there is not a corresponding decrease in EAR. In that case the MTM will increase by the amount of resources used not compensated for by a decrease in EAR. This increase in the MTM associated with the task is a measure of wasted or unplanned–for resources. Thus, when a task is performed to criterion (as a reference unit would perform) the MTM shows no change resulting from task performance. A task performed with better than criterion effectiveness will generate a decrease in the MTM, while a task performed with less than criterion effectiveness will generate an increase in the MTM.

EAR is a function of the state variables providing a prediction of the additional resources (or in general, the additional quantities defined by the MOE) required to complete the mission (from the present state). Since it is a function of mission state, it provides the prediction for all possible mission states. According to the maximum principle, knowledge of the EAR function is a necessary condition of assessing the impact of task performance on mission effectiveness. EAR is developed to represent the expected resources required assuming a reference battle group is performing the mission. It is used as a criterion standard for assessing effectiveness of any command group.

The reference EAR function is constructed using data available from many sources. It represents the expected performance of a unit executing tasks to criterion level. The primary sources of information are data describing command crews operating mission simulations and operating in the field. Data from other operational and training simulations may also be useful provided that they incorporate models of human task performance and all necessary state variables. Since the EAR is a function of the state variables, data from performances with greatly different state trajectories (paths through the state space) can be incorporated and, in fact, are necessary to build the EAR function.

The MTM measure being developed consists of an algorithm for scoring tasks as they are performed. The form of the MTM measure is paper description and documentation, as well as a developmental version of the software required to implement the measure calculations.

Application of the measure to user testing of command systems will include assisting in the test planning by identifying the tasks critically impacted by the particular command system being tested, identifying the variables to observe during testing and conditions in which the data should be collected, and defining the analyses to be performed on the data to assess task performance and mission effectiveness. The software for implementing the MTM measure will function on a PC or compatible machine.

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SMART BUS MONITORING

IN LIVE FIRE OPERATIONAL TESTING

OF 155mm HOWITZERS

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ABSTRACT

SMART BUS MONITORING
IN LIVE FIRE OPERATIONAL TESTING
OF 155mm HOWITZERS

Recent Independent Operational Test and Evaluation of weapon systems with integrated computers has presented a technical challenge involving monitoring the weapon and computer's performance without interfering with the crew's performance. The Sergeant York antiaircraft gun operational test is an example in which the fire control system was monitored by a tape recorder and huge quantities of raw data were collected. The problem was that the ratio of useful versus useless data was very small and that processing the data was so time consuming and resource intensive that very little information was derived. From that test came recognition of the practical need to monitor computers more effectively given the increasing use of embedded computer systems in weapon systems. At the U.S. Army Operational Test and Evaluation Agency (OTEA), the process became known as "smart bus monitoring" because the only part of the computer that could be tapped without interfering with the computer's internal functioning was the data bus that linked distributed computer processors to each other. "Smart" referred to the practice of recording only selected data in real time.

OTEA and TEXCOM's Field Artillery Board conducted operational tests of a platoon of M109A5 (Howitzer Improvement Program (HIP)) and a platoon of M109A2/A3 155mm self propelled howitzers in the summer of 1989. The semi-autonomous howitzers (HIPs) were product improved versions of the M109A2/A3 with new fire control computers having integrated land navigation capability. The test was planned as a series of four day, live fire exercises conducted at a war fighting tempo, however, the strict safety restrictions needed to fire approximately 30,000 rounds of high explosive 155mm artillery from semi-autonomous howitzers interfered with the realism of this plan.

The challenge was to allow the crews to safely fire at war fighting rates and collect C2 and performance data without delaying or interfering with crew functions.

It was decided that real time monitoring of the MIL-STD-1553 data bus in the HIP Automated Fire Control System (AFCS) would provide information on fire mission orders, AFCS measures of self location, gun tube azimuth, quadrant and cant. BDM International, Inc., was contracted to design, integrate and build a palletized system that would be mounted on the firing howitzers to perform these functions. The system became known as the Automated Range Safety Instrumentation System (ARSIS). The paper is a description of ARSIS functional requirements, technical solutions, and lessons learned for future applications.

SMART BUS MONITORING IN LIVE FIRE OPERATIONAL TESTING OF 155mm HOWITZERS

INTRODUCTION

In June 1987, the United States Army Operational Test and Evaluation Agency (OTEA), contracted BDM International, Inc. to evaluate alternative approaches and costs of a conceptual instrumentation system for automated range safety and data collection. The instrumentation was to be used for operational testing of the Howitzer Improvement Program (HIP), an improved version of 155mm self-propelled howitzer now in use by U.S. and NATO forces. Development of the instrumentation system was undertaken by BDM in a collaborative effort with OTEA, US Army Test and Experimentation Command (TEXCOM), and Project Manager HIP. This paper describes some of the features of the Automated Range Safety Instrumentation System (ARSIS), as the system came to be named, and states some lessons learned about the utility of being able to "see into the brain" of complex automated weapon systems in operational conditions.

First, however, credits are due to the many organizations that contributed to the ARSIS effort. USA TEXCOM's MAFIS technology provided the basic architectural structure along with MIL-STD hardware. The MAFIS equipment was extensively modified by BDM who was the MAFIS builder and had extensive understanding of that equipment. USA TEXCOM's Field Artillery Board (FAB) provided technical guidance for the ARSIS design and a key software module for calculating safety fans. The FAB conducted live fire tests on the ARSIS over a period of several months prior to the HIP operational test. The FAB also conducted the HIP operational test and used ARSIS extensively. The Office of the Program Manager HIP provided extensive technical documentation, a HIP howitzer, and participated in all design reviews. BMY and Honeywell Corp., the HIP and fire control system builders respectively, provided technical advice and access to some of their unique hardware. The USA Sacramento Army Depot and Redstone Arsenal provided material and engineering advice on the use of the North Seeking Gyro. Finally, credit must go to Major General James Drummond, then Commander USA OTEA, for recognizing the utility of advanced instrumentation and the role it will play in future Army weapon evaluations.

PROBLEM

To support a HIP production decision, the Army planned to conduct a side-by-side operational test of a platoon of M109A5 (HIP) and a platoon of M109A2/A3 self-propelled howitzers during the spring of 1989. The HIP howitzers were a product improvement of the M109A2/A3 which included an on-board fire control computer integrated with a land navigation capability. The improvements would allow the HIP howitzers to operate in an autonomous or semi-autonomous mode. The test was planned as a series of four day, live fire exercises conducted at a war fighting tempo; however, the strict safety restrictions needed to fire approximately 30,000 rounds of high explosive 155mm artillery from semi-autonomous howitzers interfered with the realism of this plan.

The challenge was to allow the crews to fire safely at war fighting rates and to collect C2 and performance data without delaying or interfering with crew functions.

UNDERSTANDING

The main requirement driving the development of ARSIS was the need for safe and realistic testing of artillery systems. The completed ARSIS was to support HIP testing by providing a safety solution for each howitzer within 30 seconds of receipt of the fire mission.

BDM was asked to evaluate alternative solutions for two separate instrumentation requirements: (1) perform high speed/high volume data collection, and (2) perform autonomous independent and rapid safety verification.

The HIP's fire control computer, Automated Fire Control System (AFCS), was a series of processors connected by a MIL-STD-1553B data bus. The AFCS provided for processing of incoming and outgoing digital messages, processing of Modular Azimuth Position System (MAPS) navigational information, computation of howitzer firing data, pointing of the armament system, and system diagnostics and prognostics. The requirement was to capture the information on this data bus for subsequent processing and analysis.

Safety verification required the independent validation of the HIP's location, the pointing direction of the armament system, and the comparison of firing data to established range safety boxes.

SOLUTION

Because rapid development of the instrumentation systems was necessary, the decision was made to use, when possible, government inventory and/or off-the-shelf hardware and software. In the course of the initial study, it was discovered that a single system could perform both the automated safety function and the data collection function. The prototype development of the ARSIS system began in October 1987. The full-scale development program to produce five systems and complete the test and integration began in August 1988. The prototype ARSIS was evaluated by the FAB at Ft. Sill, Oklahoma, prior to Initial Operational Testing and Evaluation (IOT&E) of the HIP which occurred in June and July of 1989.

A key feature of the solution was the capability to collect data without interfering with howitzer operations. The ARSIS design provides for a direct connection to the howitzer's AFCS. By monitoring the AFCS bus, the analyst had a concise record of relevant test data. A critical aspect of this AFCS Monitor was the ability to sort the messages from the bus in real time. Given the million cycles per minute rate of the MIL-STD-1553B data bus, this ability to be selective greatly reduced the volume of unneeded data. The messages which were disregarded were the Stay Alive Status Messages, the Cannon-Orientation messages, and duplicates of messages already logged. The AFCS Monitor design provided four Megabytes of solid state memory storage for test data for post-test analysis. Combined with high-speed serial data transfer capability, this unit provides a highly reliable and efficient method of capturing data in a field environment. The benefit of this smart bus monitor was significant in terms of manpower, instrumentation cost, and accuracy.

The AFCS on board each howitzer independently processed the firing data for the howitzer. The role of ARSIS was to verify independently that the aim of the cannon falls within the safety limits for azimuth and quadrant elevation as determined by the embedded computer program. The calculation was based on target area, battery position, weapon system, caliber, type of projectile, fuze, and charge. The safety limits generated by this program were used to determine if the howitzer's AFCS generated firing calculation met the range safety criteria. ARSIS independently determines position location, azimuth, and quadrant elevation, then compared this information with the AFCS values and the safety limits, which provided an automatic verification of safety. If the two sets of howitzer status information (position location and gun-aiming parameters) agreed within user-set tolerances, and if both were within the safety limits, the ARSIS determined a safe condition and notified the safety officer. A variable delay can be set for the safety officer to assess the howitzer status prior t- ARSIS automatically sending a "safe status" indicator to the howitzer Chief of Section. The system also provided for safe/unsafe overrides by the safety officer (man-in-the-loop).

SYSTEM DESCRIPTION

The ARSIS system (Figure 1) comprises two subsystems. The howitzer instrumentation subsystem (HIS) performs data collection/storage, position location, and gun tube orientation measurements. The safety officer's instrumentation subsystem (SOIS) provides autonomous safety evaluation/verification. The two instrumentation sets communicate via an RF modem.

1. Howitzer Instrumentation Subsystem (HIS)

Figure 2 shows the HIS which consists of the ARSIS Integrated Field Element (AIFE), and other instrumentation. The HIS uses a separate power source (batteries) to preclude any interference with the howitzer power system.

A. ARSIS Integrated Field Unit (AIFE)

The AIFE, the heart of the HIS, is a very compact collection of the four processing modules: the DCP, the ARSIS Data Link, the Position Location Sensor, and the AFCS Monitor. The AIFE design made heavy use of existing hardware and software which was developed by BDM for U.S. Army MAFIS program. The AIFE occupies less than one cubic foot of volume, consumes less than 35 watts of power, and weighs approximately 27 lbs.

1) Data Collection Processor (DCP)

The DCP is the central processor and controller for the HIS and provides for the collection and preprocessing of the measurement sensor data. The DCP contains an altitude lookup table derived from the Defense Mapping Agency's digitized terrain data for Fort Sill. This data base is used by the DCP to look up the corresponding vertical component of the horizontal position. The DCP interfaces directly with the AFCS Monitor, Data Signal Processor, radio data link, and Position Location Sensor.

2) ARSIS Data Link

The data link is an off-the-shelf RF modem which operates at 1200 bits per second. It was integrated within the AIFE both electrically and mechanically to become part of this compact unit. It provides half-duplex communications with the SOIS on a single frequency in the 400 MHz band. Each howitzer/safety-officer-vehicle pair operates on different frequencies.

3) Position Location Sensor (PLS)

The PLS performs the computations required to generate latitude/longitude position estimates for the host platform. It is an off-the-shelf circuit board which was also integrated into the AIFE enclosure. This unit is based upon the LORAN system and provides the ability to track up to four chains simultaneously. This cross-chain operation is needed due to the poor LORAN coverage from any single chain at Fort Sill. The DCP takes the position estimate from the PLS and transforms it into UTM coordinates. Due to the poor LORAN-transmitter geometry at Fort sill, a reference station at a known location is used to generate position offsets which are entered into the SOIS manually, sent via RF modem to the DCP, and incorporated for an improved position estimate. Extensive testing showed that this simple differential correction scheme resulted in position accuracies of approximately 50 meters, 70 meters and 95 meters for 50%, 70%, and 95% confidence intervals respectively.

4) Automated Fire Control System (AFCS) Monitor

The AFCS monitor serves as a MIL-STD-1553B bus monitor. The heart of this unit is an advanced, off-the-shelf, bus controller/monitor which was integrated with a central processing unit and with nonvolatile, solid state, memory boards to complete a unit capable of stand-alone operation. Data from the AFCS is sorted as discussed above and logged for later retrieval. In addition, to support the safety assessment, key fire mission parameters, HIP position location, and gun-attitude measurements are extracted from various messages in the bus traffic and packaged for transfer to the DCP where they are put together with other sensor data for transmittal to the safety officer instrumentation. The data critical to ARSIS operation that appears on the AFCS bus include shell type and weight; charge and fuze type and setting; target information; derived howitzer position; and the gun-tube azimuth and quadrant elevation as determined by the AFCS. A critical and challenging aspect of the AFCS Monitor design was being able to develop a state machine which could track the mission sequencing for different mission types given a moving target in the AFCS software development itself. This state machine was required to track the howitzer status at any given time and keep the safety officer appraised of the situation.

5) Data Signal Processor (DSP)

The DSP is a newly-designed item which interfaces to the azimuth sensor and converts the analog data from the quadrant elevation and cant sensor into digital form. Instead of a commercially available analog/digital (A/D) converter/processor card in the DCP, a separate processor was used for this function which reduced the risk of introducing noise on the analog signal lines. The DSP also included the red/green (GO/NO-GO) indicator lights which displayed the safety status to the Chief of Section.

B. Azimuth Sensor

The azimuth sensor measures the azimuth of the gun tube relative to north. It provides this information to the DCP via the DSP. The selected unit was a mil spec Gyro and was chosen, because it is highly accurate (nominally 1 mil), shock-hardened, and currently in the U.S. Army inventory.

C. Quadrant Elevation (QE) and Cant Sensors

The QE sensor measures gun tube elevation angle above and below the local horizontal. The cant sensor measures how far the gun trunnion is "tilted to the side" relative to the local horizontal. The two sensors are mounted at a 90 degree angle relative to each other. The off-the-shelf inclinometers used for the QE and cant sensors were selected because they are small enough to be mounted directly to the cannon trunnion, rugged enough withstand shocks in excess of 300 g's during firing of the howitzer and accurate enough to permit 1 mil resolution of the gun tube placement. Special calibration procedures are used to perform the electrical and mechanical alignment of these inclinometers as well as for the azimuth sensor.

D. <u>Reference Timing Unit (RTU)</u>

The RTU is a synchronized time-code generator which permits accurate time tagging of all data collected and recorded during the test. These time tags allow an analyst to reconstruct the events of the test in chronological order. The RTU is a ruggedized off-the-shelf unit which can be synchronized to Universal Time at the beginning of a test and then "free run" using its own internal oscillator to maintain time until the next update. This approach was selected to eliminate the need for another antenna and for continuous monitoring of an external timing signal.

E. <u>Power Distributions Unit (PDU)</u>

The PDU was designed to distribute 24 VDC power from a pair of 12 volts marine batteries to the other HIS elements. The independent power source provides approximately 10 hours of continuous operation and avoids the possibility of any ARSIS equipment affecting the performance of the howitzer during testing. The PDU also contains switching and charging circuitry for a small set of secondary batteries contained within which permit the changing of the primary batteries without having to interrupt system operation.

2. <u>Safety Officer Instrumentation Subsystem (SOIS)</u>

The Safety Officer Instrumentation System (SOIS) receives data from the HIS and uses subroutines furnished by the U. S. Army Field Artillery School (USAFAS) to determine if the howitzer is safe to fire. The SOIS includes a graphics display to show the safety "T" and provides a tabular display of fire mission data, sensor readings, and operational states. It also shows the safety officer where the howitzer gun-tube is positioned in relation to the safety limits. The SOIS (Figure 3) consists of an Automated Safety Processor (ASP), DC/AC Power Invertor, Reference Timing Unit (RTU), Power Distribution Unit (PDU), Power Conditioning Unit (PCU), and Data Link. The Data Link and PDU are essentially the same units used in the HIS described above.

A. <u>Automated Safety Processor (ASP)</u>

The ASP is an off-the-shelf, ruggedized, IBM-PC/AT compatible computer. The DC/AC invertor is an off-the-shelf unit which permits the ASP to operate off the host-vehicle 28 VDC power source. The electro-luminescent display provides the safety officer easy viewing at night. The ASP uses fire mission parameters sent over the data link, a target area file, and subroutines to calculate the safety limits for the given weapon type and position of the howitzer. HIP and ARSIS independent sensor parameters are compared and checked against the safety limits to determine the safety state.

B. <u>Power Conditioning Unit (PCU)</u>

The PCU for the SOIS is needed to suppress spikes and filter the 28 volts of the vehicle power sou . It will suppress spikes of up to 250 volts and will filter the 28 volts, limiting output ripple to no more than 2 volts peak-to-peak over a steady state range of 22-30 volts.

PERFORMANCE

The overall performance of ARSIS during the HIP IOT&E was highly successful. The range safety function provided the Safety Officers with timely safety information which accounted for a test with no range safety incidents while firing almost 20,000 rounds under stressful operational conditions.

The data collection function was equally successful in that over 200,000 kilobytes of information was captured from the AFCS. This information became the core data for the analysis of the overall performance of the HIP howitzer. The data was originally planned to be used only in the assessment of the AFCS software's performance. However, early in the test the HIP analysts recognized that the ARSIS data was an extremely accurate data source for a range of system performance information. Examples of the utility of the ARSIS collected data includes:

* howitzer crew response times under every test condition.

* identification of all fire mission parameters; target grid, target number, fired shell, fuze, powder type, quadrant and azimuth, and receipt and fired times.

* precise timing of all ballistic calculations.

* precise record of all digital communications received and sent by the HIP howitzers.

LESSONS LEARNED

OTEA's Fire Support Directorate (FSD), is responsible for conducting operational tests and evaluations of artillery systems. As a result of the HIP IOT&E, ARSIS has provided a new capability to exercise indirect fire support systems in realistic and safe tests. Possible future applications include the next generation of shoot-and-scoot rocket launchers, howitzer systems, and, potentially, armored systems as well. The principal impact will be seen in crew training when previously closed training areas are reopened to realistic live fire exercises, as the risk or training mistakes are reduced. Now that the ARSIS pioneering effort is over, sufficient expertise is available to guide the development of a less expensive, more compact system that can be strapped on as units enter the live fire training phase. The long term benefit will be better trained fighting crews and a more effective ground force to carry out the U.S. Army mission. Other specific lessons learned consisted of:

1. The use of off-the-shelf components such as ruggedized computers, radios, north-seeking gyrocompasses, and position-location

sensors provided a relatively low cost and effective method of achieving the desired result without the usual hardware development time. While some items were far more reliable than other, careful integration of these components using a test-fix-test philosophy did result in a successful test program.

2. Nonvolatile data storage is necessary to ameliorate the effects of inadvertent data loss. A data transfer media which can be protected from the dirt/dust environment is also critical. Also, with larger amounts of data being collected, the size limitations of floppy disks are close to being exceeded.

3. As complex instrumentation systems interact with even more complex host systems-under-test, the ability to diagnose problems, especially subtle conditions, becomes increasingly difficult. The need for quality diagnostics is paramount to an efficient test operation, and design-for-testability guidelines should be enforced as strictly as quality control.

4. An important requirement is for a solid test operations and maintenance support methodology and detailed support plan. This requirement, however, must be tempered with the flexibility required by test realities. This area is one in which a dedicated team of professionals who have a vested interest in the success of the test can make the difference.

5. The ability of a system such as ARSIS to provide a real time MIL-STD-1553B data collection/sorting mechanism for AFCS data is a major breakthrough for test and training applications. Over 200 Megabytes of data were collected during this test. Without this data, the test would not have been nearly as effective. In addition, the evaluation of the test results was greatly enhanced by being able to upload the data into a minicomputer and manipulated it using standard ADP and statistical packages. ARSIS also provided a near real time means for computing safety limits and assessing howitzer safety status.

6. Automated safety assessments could increase the available training time by eliminating the delays due to manual safety procedures.

7. The use of this system for all artillery exercises should be investigated and the feasibility of incorporating a system as an integral part of the on-board howitzer equipment should be considered.

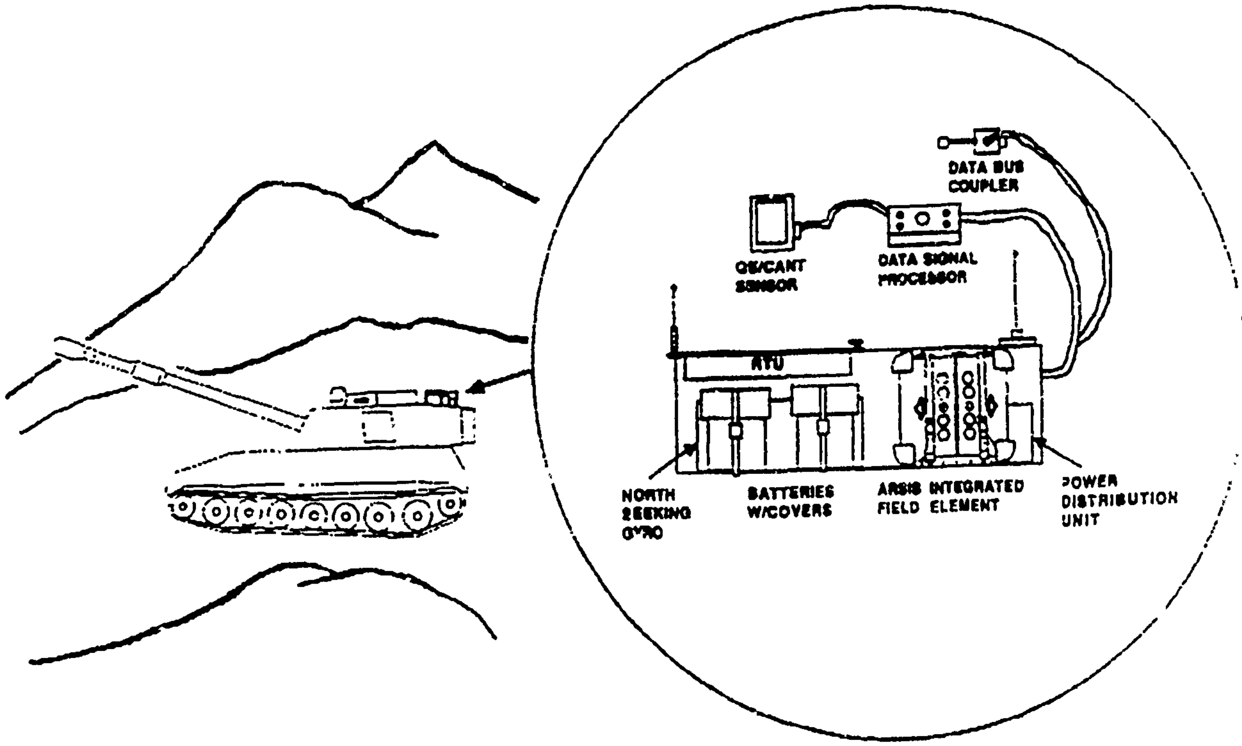

FIGURE 2: HOWITZER INSTRUMENTATION SUBSYSTEM

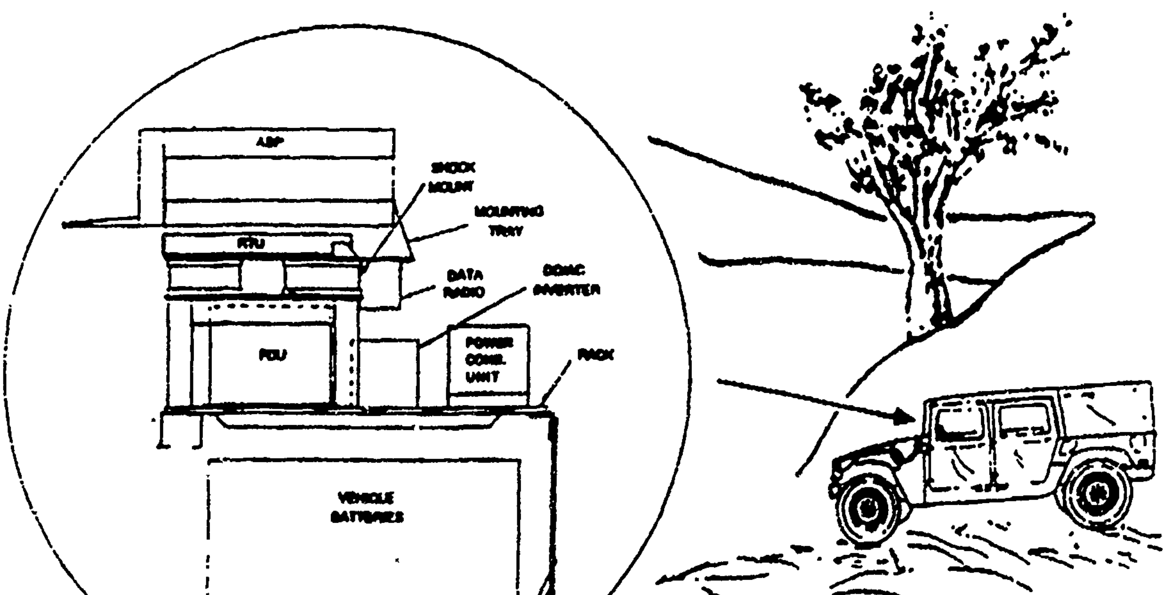

FIGURE 3: SAFETY OFFICER INSTRUMENTATION SUBSYSTEM

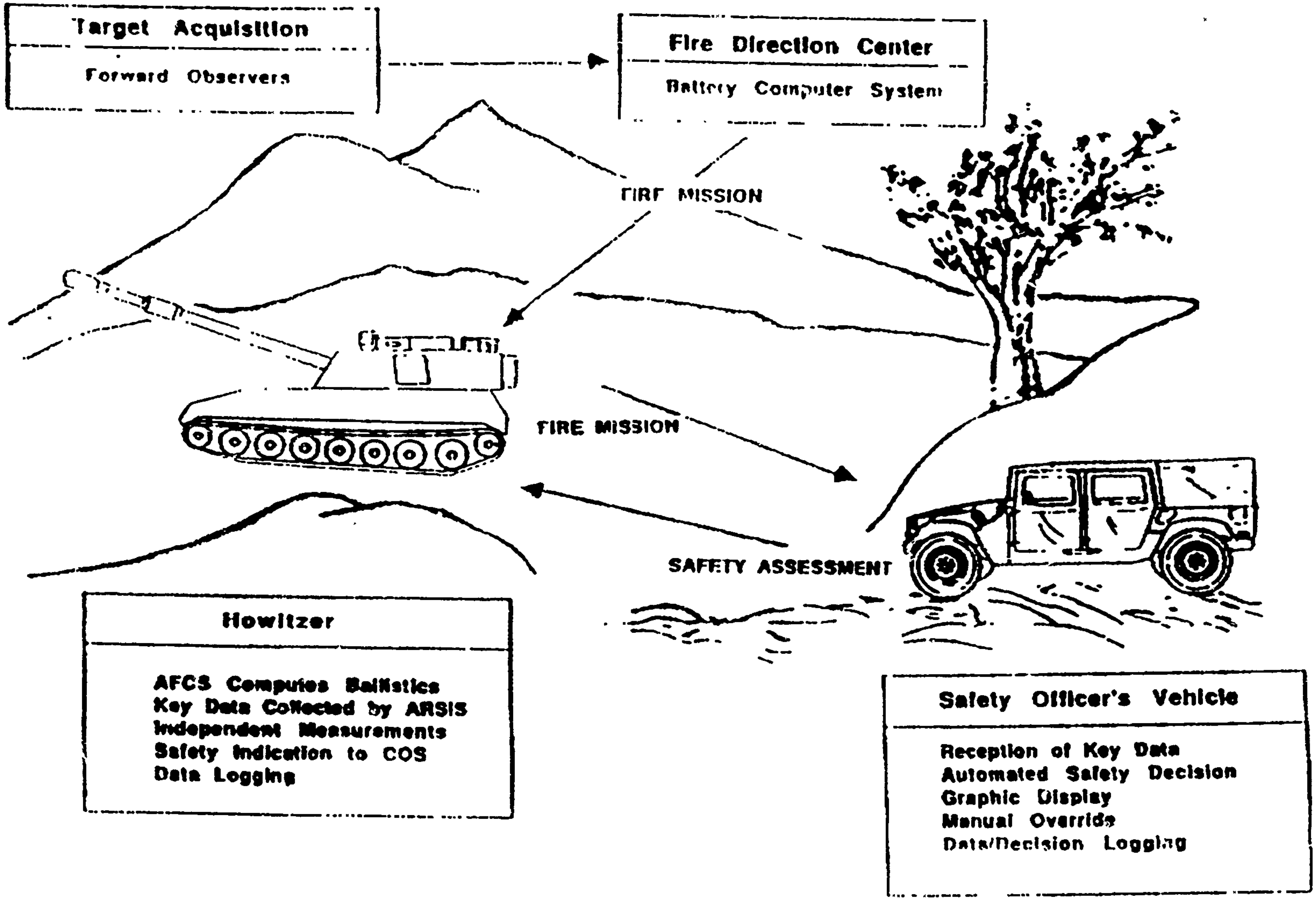

FIGURE 1: ARSIS SYSTEM CONCEPT

COMPARISON OF PARAMETRIC VERSUS NONPARAMETRIC EVALUATION UPON NON-HOMOGENEOUS FIELD DATA

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ABSTRACT

Analysis of field survey results to compare qualitative data has traditionally used non-parametric techniques when Bartlett's Test for Homogeneity of Variance has been significant or when normality could not be assumed. The Belvoir Research, Development, and Engineering Center has been using the test procedure of forced paired comparisons to evaluate desert camouflage uniforms. The desert uniforms were evaluated in all possible pairs, as to the best blend with the background. A total of ten test sites, and eight uniforms were used for this study. The Bartlett's Test for Homogeneity of Variance was significant for each site. When the parametric analysis of variance were compared with the nonparametric Mann-Whitney U-test, the Kolmogorov-Smirnov Two-Sample Test, and the Wald-Wolfowitz Runs Test, the results indicated the analysis-of-variance technique to be sufficiently robust that the use of nonparametric techniques can be eliminated.

1.0 SECTION 1 - Introduction

The U.S. Army Belvoir Research, Development, and Engineering Center has conducted desert color field evaluations since September 1980. During the course of several investigations,[1,2] a remarkable similarity in the results of the parametric One-Way Analysis of Variance (ANOVA) Test and Duncan's Multiple-Range Test to the nonparametric Kruskal-Wallis ANOVA and the Mann-Whitney U-test has been determined. Although it is noted that parametric procedures are not advised for use in this the experimental design due to the assumptions required about normality, homogeneity, and ordinality of the data, it appears that parametric ANOVA procedures are sufficiently robust that they may be applied to the experimental design. In addition, multiple-range procedures can be applied that are not available in nonparametric statistical packages.

2.0 SECTION 2 - Experimental Design

Critical to the development and application of statistical techniques is both the understanding of the underlying experimental design, and the understanding of the desired results. Occam's razor[3] applies, meaning that the simplest, most direct approach with minimal data manipulation to provide insight to the problem of interest should be used.

2.1 Test Uniforms

A total of eight desert camouflage uniforms were evaluated. The following is a description of each:

Uniform #1, the standard U.S. Army Desert Day Camouflage uniform in a six-color pattern of Light Tan 379*, Tan 380*, Light Brown 381*, Dark Brown 382*, Black 383*, and Khaki 384*.

Uniform #4, a three-color pattern of Light Tan 379*, Khaki 384*, and Light Brown 381*.

Uniform #5, a three-color pattern of Light Tan 379*, Tan 380*, and Khaki 384*.

Uniform #6, a three-color pattern of Desert Tan 459*, Khaki 384*, and Light Brown 381*.

Uniform #8, a solid-color uniform of Tan 380*.

Uniform #9, a solid-color uniform of Khaki 384*.

Uniform #10, a three-color pattern of Sand**, Khaki 384*, and Brown**.

Uniform #11, a two-color pattern of the colors clay** and Khaki 384*.

* Natick Research, Development, and Engineering Center assigned numbers.
** No numbers assigned.

2.2 Test Sites

A total of ten desert sites were selected for the study. All the sites contained sparse vegetation similar to that found in areas of interest in the Middle East. The soil ranged in color from a light tan/buff to grey and dark brown, and represented a good cross-sectional spectrum of different colored desert backgrounds. The order of the ten sites as they appear in this study is shown in Table 1.

Table 1
Site Order Identification

Site #	Color	Location
1	Buff	Yuma Sand Dunes, AZ
2	Light Gray	Ogilby Road, Tumco, CA
3	Very Light Tan	Yuma Proving Grounds, AZ
4	Dark Beige Tan	Anza Borrego State Park, CA
5	Light Tan	Tank Trail, 29 Palms, CA
6	Dark Tan	Salton Sea, CA
7	Beige Tan	Anza Borrego State Park, CA
8	Light Beige Tan	Anza Borrego State Park, CA
9	Tan	Jean Dry Lake Bed, NV
10	Gray Tan	Rt. 15, Baker, CA

2.3 Test Subjects

The test subjects consisted of operational image interpreters (IIs) from the following bases:

a. Fleet Intelligence Center, Europe and Atlantic

b. Fleet Intelligence Training Center, Pacific

c. 2nd Marine Aircraft Wing

d. 4th Marine Image Interpretation Unit

e. 3rd Marine Air Wing

f. 480th Reconnaissance Wing

g. 67th Tactical Reconnaissance Wing

h. 17th Military Intelligence Company

i. 319th Military Intelligence Battalion

The IIs were divided into teams of two to evaluate the imagery. A total of forty-one two-man teams participated in the study.

2.4 Data Generation

The object of the study was to determine which camouflage uniform color blended best with the desert backgrounds when photographed during the midday sunlight. The teams of image interpreters (41) were shown all possible pairs of uniforms for each of the ten sites. They were told to select the uniform that best blended with the desert background. No ties were allowed. The number of times a uniform was preferred by each observer at each site was totalled. Thus, each uniform could be ranked from 0 (not preferred over any uniform) to 7 (preferred over all other uniforms).

2.5 Analysis

The original data analysis was reported 26 July 1988[4/]. ANOVA tables, including the Duncan's Multiple-Range Test and the Mann-Whitney U-Tests, were presented. After close examination, both methods appeared to give similar results. The problem of normality was not considered significant, as literature suggested that normality was not a significant issue with the ANOVA procedure, as long as the sample were roughly equal, or large numbers of observations per cell were included.[4] However, of more concern was the problem of homogeneity of the variance, since the Bartlett's-test homogeneous variances were significant. With the large availability of statistical packages, a larger number of statistical tests are available to run a wider range of statistical routines. This paper presents the results of that investigation.

3.0 SECTION 3 - Results

All statistical routines discussed here were run for each site and all sites combined. Only the data from all sites combined, and a summary for each individual site, will be presented. The individual test-site test results are available upon request from the U. S. Army Belvoir Research, Development, and Engineering Center, ATTN: STRBE-JDA, Fort Belvoir, VA 22060-5606.

3.1 Parametric Results

In order to perform the multiple-range tests, an ANOVA procedure was invoked. A mean preference rating and 95% confidence interval is presented in Table 2 for all sites combined. Figure 1 presents graphically the results of the 95% confidence level.

Table 2
Mean Preference Rating and 95 Percent Confidence Intervals
for Blending with Background - All Sites

Uniforms	N	Mean	Standard Error	95% Confidence Interval Lower Limit	Upper Limit
1	410	1.6805	.0881	1.5073	1.8536
4	410	5.1634	.0663	5.0332	5.2937
5	410	5.3000	.0572	5.1876	5.4124
6	410	3.3098	.1111	3.0914	3.5281
8	410	3.8732	.0640	3.7473	3.9990
9	410	0.5902	.0365	0.5185	0.6620
10	410	4.7244	.0714	4.5840	4.8648
11	410	3.3558	.0916	3.1784	3.5387

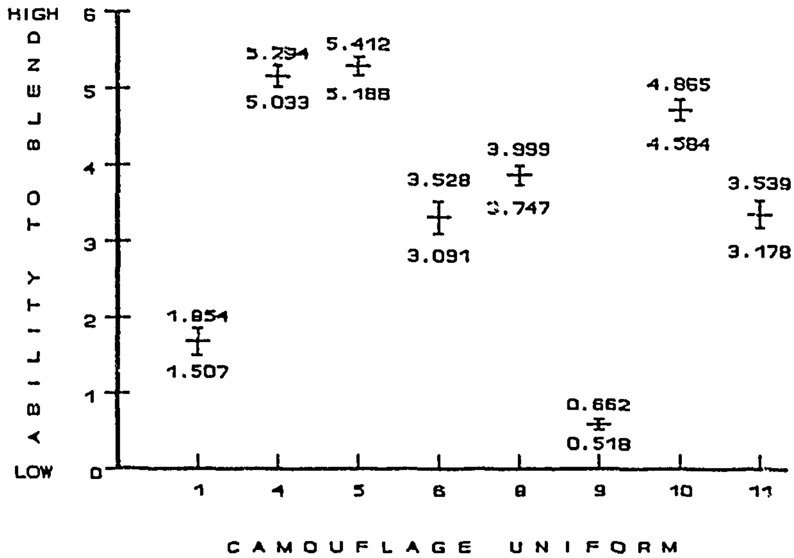

Figure 1. Mean Preference Rating & 95% Confidence Intervals for Blending with Background - All Sites

Table 2 gives the descriptive data for all sites combined. Table 3 provides the ANOVA results to determine if significant differences exist between uniforms in their ability to blend with the desert background when averaged across all sites. The analysis of variance indicates that there are significant differences in camouflage effectiveness of the uniforms, as determined by the image interpreters. The Bartlett's Test (Table 3) indicates that the variances for each uniform level are not homogeneous, i.e., significantly different. They are not from the same population.

Table 3
Analysis of Variance of Camouflage Uniforms for All Sites

Source	Degrees of Freedom	Sum of Squares	Mean Square	F-Test	Level
Uniforms	7	7986.3268	1140.9038	476.7807	0.000*
Within Groups	3272	7829.6732	2.3929		
Total	3279	15816.0000			

Bartlett's Test for Homogeneous Variances
Degrees of Freedom = 7
F = 83.652, P = 0.000*

*Significant at α less than 0.001 level

3.1.1 Duncan's Multiple-Range Test

Tables 4 and 5, using Duncan's Multiple-Range Test, separate these uniforms into homogeneous groups, thus identifying which groups of uniforms blend well with the desert background, and which groups of uniforms do not blend.

Table 4
Duncan's Multiple-Range Test
(Ability to Blend with Background) for All Sites

WORST SUBSET 1	SUBSET 2	SUBSET 3	SUBSET 4	SUBSET 5	BEST SUBSET 6
Uniform #9	Uniform #1	Uniform #6	Uniform #8	Uniform #10	Uniform #4
Mean 0.5902	Mean 1.6805	Mean 3.3098	Mean 3.8732	Mean 4.7244	Mean 5.1634
		Uniform #11			Uniform #5
		Mean 3.3585			Mean 5.3000

Table 5
Duncan's Multiple-Range Test
(Ability to Blend with Background)
Summary of Best Subset For Each Site and All Sites

Sites	Uniforms 1	4	5	6	8	9	10	11
All Sites		X	X					
Site 1			X		X		X	
Site 2		X	X					X
Site 3		X	X				X	
Site 4		X	X					
Site 5				X				
Site 6				X			X	
Site 7		X	X					
Site 8			X					
Site 9		X	X					
Site 10				X			X	

3.1.2 Least Significant Difference (LSD) Multiple-Range Test

Duncan's Multiple-Range Test is one of the least conservative multiple-range tests that could be performed. In order to compare more conservative tests to that of the nonparametric results, additional multiple comparisons should be run to compare results. Table 6 provides the results of the Least Significant Difference Multiple Range Procedure for all sites combined. Table 7 provides a summary of the best subset for each individual site, and across all sites.

Table 6
Least Significant Difference (LSD) Multiple-Range Procedure
(Ability to Blend with Background) for All Sites

WORST SUBSET 1	SUBSET 2	SUBSET 3	SUBSET 4	SUBSET 5	BEST SUBSET 6
Uniform #9	Uniform #1	Uniform #6	Uniform #8	Uniform #10	Uniform #4
Mean 0.5902	Mean 1.6805	Mean 3.3098	Mean 3.8732	Mean 4.7244	Mean 5.1634
		Uniform #11			Uniform #5
		Mean 3.3585			Mean 5.3000

Table 7
Least Significant Difference (LSD) Multiple-Range Procedure
(Ability to Blend with Background)
Summary of Best Subset For Each Site and All Sites

Sites	Uniforms 1	4	5	6	8	9	10	11
All Sites		X	X					
Site 1			X		X		X	
Site 2		X	X					X
Site 3		X	X				X	
Site 4		X	X					
Site 5				X				
Site 6				X			X	
Site 7		X	X					
Site 8			X					
Site 9		X	X					
Site 10				X			X	

3.1.3 Tukey's Alternate Test Multiple-Range Procedure

Table 8 provides the results of the Tukey's Alternate Test Multiple-Range Procedure for all sites combined. Table 9 provides a summary of the best subset for each individual site, and across all sites.

Table 8
Tukey's Alternate Multiple-Range Procedure
(Ability to Blend with Background) for All Sites

WORST SUBSET 1	SUBSET 2	SUBSET 3	SUBSET 4	SUBSET 5	BEST SUBSET 6
Uniform #9 Mean 0.5902	Uniform #1 Mean 1.6805	Uniform #6 Mean 3.3098	Uniform #8 Mean 3.8732	Uniform #10 Mean 4.7244	Uniform #4 Mean 5.1634
		Uniform #11 Mean 3.3585			Uniform #5 Mean 5.3000

Table 9
Tukey's Alternate Multiple-Range Procedure
(Ability to Blend with Background)
Summary of Best Subset For Each Site and All Sites

Sites	Uniforms 1	4	5	6	8	9	10	11
All Sites		X	X					
Site 1		X	X		X		X	
Site 2		X	X					X
Site 3		X	X				X	X
Site 4		X	X					
Site 5				X			X	
Site 6				X			X	
Site 7		X	X					
Site 8			X					
Site 9		X	X					
Site 10			X	X			X	

3.1.4 Tukey's Honestly Significant Difference (HSD) Multiple-Range Procedure

Table 10 provides the results of the Tukey's Honestly Significant Difference Multiple Range Procedure for all sites combined. Table 11 provides a summary of the best subset for each individual site, and across all sites.

Table 10
Tukey's Honestly Significant Difference (HSD) Multiple-Range Procedure
(Ability to Blend with Background) for All Sites

WORST					BEST
SUBSET 1	SUBSET 2	SUBSET 3	SUBSET 4	SUBSET 5	SUBSET 6
Uniform #9	Uniform #1	Uniform #6	Uniform #8	Uniform #10	Uniform #4
Mean 0.5902	Mean 1.6805	Mean 3.3098	Mean 3.8732	Mean 4.7244	Mean 5.1634
		Uniform #11			Uniform #5
		Mean 3.3585			Mean 5.3000

Table 11
Tukey's Honestly Significant Difference (HSD) Multiple-Range Procedure
(Ability to Blend with Background)
Summary of Best Subset For Each Site and All Sites

Sites	Uniforms 1	4	5	6	8	9	10	11
All Sites		X	X					
Site 1		X	X		X		X	
Site 2		X	X					X
Site 3		X	X				X	X
Site 4		X	X					
Site 5				X			X	
Site 6				X			X	
Site 7		X	X					
Site 8			X					
Site 9		X	X					
Site 10			X	X			X	

3.1.5 Scheffe's Multiple-Range Procedure

Table 12 provides the results of the Scheffe's Multiple-Range Procedure for all sites combined. Table 13 provides a summary of the best subset for each individual site, and across all sites.

Table 12
Scheffe's Multiple-Range Procedure
(Ability to Blend with Background) for All Sites

WORST					BEST
SUBSET 1	SUBSET 2	SUBSET 3	SUBSET 4	SUBSET 5	SUBSET 6
Uniform #9	Uniform #1	Uniform #6	Uniform #8	Uniform #10	Uniform #4
Mean 0.5902	Mean 1.6805	Mean 3.3098	Mean 3.8732	Mean 4.7244	Mean 5.1634
		Uniform #11			Uniform #5
		Mean 3.3585			Mean 5.3000

Table 13
Scheffe's Multiple-Range Procedure
(Ability to Blend with Background)
Summary of Best Subset For Each Site and All Sites

Sites	Uniforms							
	1	4	5	6	8	9	10	11
All Sites		X	X					
Site 1		X	X		X		X	
Site 2		X	X					X
Site 3		X	X				X	X
Site 4		X	X					
Site 5				X			X	
Site 6				X			X	
Site 7		X	X				X	
Site 8			X					
Site 9		X	X					
Site 10		X	X	X			X	

3.2 Nonparametric Results

Nonparametric results are far more difficult to generate on most statistical packages, as the statistical packages in general do not include a procedure to perform multiple comparisons as is the case for parametric procedures. After a k-sample Kruskal-Wallis One-Way ANOVA procedure is performed, and a significant difference is found, the experimenter must proceed with individual comparisons between groups. From an experimental point of view, this increases the probability of finding two or more groups that differ to an unacceptable level. The Kruskal-Wallis One-Way ANOVA for all sites combined is reported in Table 14.

Table 14
Kruskal-Wallis One-Way ANOVA
Nonparametric Procedure
for Desert Uniforms for All Sites

Uniform	Mean Rank	Cases
1	869.53	410
4	2355.01	410
5	2416.62	410
6	1554.22	410
8	1778.95	410
9	421.48	410
10	2161.03	410
11	2567.17	410
Total		3280

			Corrected for Ties	
CASES	Chi-Squared	Significance	Chi-Squared	Significance
3280	1598.3970	0.0000*	1625.0910	0.0000*

*Significant at $\alpha \leq .0001$

3.2.1 Mann-Whitney U-Test Procedure

Table 15 provides the results of the nonparametric Mann-Whitney U-Test Procedure for all sites combined. Table 16 provides the Mann-Whitney U-Test Procedure Summary of the best subset for each individual site, and across all sites.

Table 15
Mann-Whitney U-Test Procedure
for Desert Uniforms for All Sites

Uniform	Uniforms 1	4	5	6	8	9	10	11
1								
4	***							
5	***	-						
6	***	***	***					
8	***	***	***	***				
9	***	***	***	***	***			
10	***	***	***	***	***	***		
11	***	***	***	-	***	***	***	

Key
- \- α = Not Significant
- * α ≤ .05
- ** α ≤ .01
- *** α ≤ .001

Table 16
Mann-Whitney U-Test Procedure
(Ability to Blend with Background)
Summary of Best Subset For Each Site and All Sites

Sites	Uniforms 1	4	5	6	8	9	10	11
All Sites		X	X					
Site 1					X		X	
Site 2		X	X					X
Site 3		X	X				X	
Site 4		X	X					
Site 5				X				
Site 6				X			X	
Site 7		X	X				X	
Site 8			X					
Site 9		X	X					
Site 10				X			X	

3.2.2 Kolmogorov-Smirnov Two-Sample Test Procedure

Table 17 provides the results of the nonparametric Kolmogorov-Smirnov Two-Sample Test Procedure for all sites combined. Table 18 provides the Kolmogorov-Smirnov Two-Sample Test Procedure Summary of the best subset for each individual site, and across all sites.

Table 17
Kolmogorov-Smirnov Two-Sample Test Procedure
for Desert Uniforms for All Sites

Uniform	Uniforms 1	4	5	6	8	9	10	11
1								
4	***							
5	***	-						
6	***	***	***					
8	***	***	***	***				
9	***	***	***	***	***			
10	***	***	***	***	***	***		
11	***	***	***	**	***	***	***	

Key
- - α = Not Significant
- * $\alpha \leq .05$
- ** $\alpha \leq .01$
- *** $\alpha \leq .001$

Table 18
Kolmogorov-Smirnov Two-Sample Test Procedure
(Ability to Blend with Background)
Summary of Best Subset For Each Site and All Sites

Sites	Uniforms 1	4	5	6	8	9	10	11
All Sites		X	X					
Site 1			X		X		X	
Site 2		X	X					X
Site 3		X	X				X	X
Site 4		X	X					
Site 5				X				
Site 6				X			X	
Site 7		X	X					
Site 8			X					
Site 9		X	X					
Site 10				X				

3.2.3 Wald-Wolfowitz Runs Test

The Wald-Wolfowitz Runs Test was to be used as a nonparametric procedure to evaluate the results of individual comparisons of two uniforms, as it is extremely general and consistent against all types of differences in the population. However, subsequent research found theoretical problems as a result of ties across samples.[6] As a result, this procedure could not be used, since the test statistic becomes indeterminate.

4.0 SECTION 4 - Discussion

A review of the data for sites 1-10 and for all sites combined indicates that camouflage uniforms 4 and 5 are the most effective in blending with the desert terrain (Tables 5, 7, 9, 11, 13, 16 & 18). Although uniforms 4 and 5 were not among the best uniforms on sites 1, 5, 6, 8 and 10 using Duncan's Multiple-Range Test, or the Least Significant Difference Multiple-Range Test (Tables 5 & 7), all nonparametric test procedures (Tables 16 and 18) and all other parametric test procedures (Tables 9 & 11) include uniforms 4 and 5, except for sites 5, 6 and 8. These uniforms had an overall mean blending value of 5.1634 and 5.3000 respectively

(Table 2). Among individual sites, all parametric Multiple-Range tests and nonparametric individual comparisons show remarkable consistency.

Both nonparametric techniques used are consistent and provide identical results. However, these tests are equivalent to the two-sample t-test. As a result, the risk of a Type I error, i.e. the probability of rejecting a true hypothesis, is much higher than for the stated α.[7] As a result, a Multiple-Range test would be preferred. Though there is no widely recognized nonparametric multiple-range test that can be easily applied, there are several recognized and established multiple-range tests that can be applied in conjunction with the ANOVA procedure.

Differences between parametric tests can be attributed to how conservative the specific multiple-range test is. The parametric tests are presented in order of least conservative to most conservative, although there is no difference between these tests for all sites combined, as the sample size is relatively large. Although the appropriateness of parametric tests are of concern, since homogeneity was a problem, as long as sample sizes are sufficiently large and equal, nonhomogeneity has a minimal impact on the power of the test.[5]

5.0 SECTION 5 - Summary and Conclusions

A total of eight desert camouflage uniforms were evaluated as to their ability to blend with the desert backgrounds in the U.S. Southwest. Ten sites were used for the study. The uniforms were viewed in all possible pairs (28). For each pair of uniforms, the image interpreters were told to select the uniform that best blended with the surrounding desert background. A total of five parametric tests and two nonparametric tests were used to analyze the resultant data. The results of this evaluation produced the following conclusions:

A. Camouflage uniforms 4 and 5 blended best overall with the desert background.

B. Parametric techniques can be used to evaluate forced paired comparisons.

C. Parametric techniques can provide adequate results in cases where homogeneity of variance is not ensured.

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COMPARISONS OF FIELD TESTS WITH SIMULATIONS: ABRAMS PROGRAM LESSONS LEARNED

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ABSTRACT

The onset of full-scale, live-fire testing (LFT) has provided vulnerability workers with unprecedented opportunities to examine field results in the light of model predictions. Pre-Abrams experience with LFT showed, however, that the extant vulnerability models lacked 1] the capability to predict component damage states (the actual field observable) and 2] the ability to reflect at least the principal forms of randomness which are intrinsic to the physical processes associated with damage.

To remedy this shortcoming, the BRL/VLD developed a new stochastic point-burst vulnerability code, called SQuASH, in which the following parameters are varied in a Monte Carlo replication of warhead/target encounters: 1] slight variability in hit location, 2] warhead depth-of-penetration, 3] deflection of residual penetrator, 4] spall generation, and 5] individual component-kill assessment.

SQuASH has been used to predict 48 shots in the Abrams LF program. Both subjective and statistical tests have been performed in an effort to compare field observations with computer predictions. These comparisons have been made both for component damage as well as Mobility-, Firepower- and Catastrophic-Kill criteria.

Just as with prior point-burst models and LFT assessments, substantial subjectivity exists in four areas: a] the identification of system critical components, b] the binning of partially functioning components into kill/no-kill categories, c] the characterization of component interconnectivity *via* the fault tree synthesis and d] the Damage Assessment List (DAL) mapping process (by which M- and F-Kill values are inferred). In order for comparability to exist between field tests and computer simulations, LFT observations must be assessed within the same analytical paradigms of a] through d].

In this paper, the vulnerability framework is described, the kinds of results yielded by the SQuASH predictions, and the lessons learned from our efforts to "calibrate" the model based on the statistical tests performed.

1. INTRODUCTION

The National Defense Authorization Act for FY 1987[1] requires that all major weapon systems undergo live-fire testing (LFT) prior to entering full-scale production. The intent is to establish the baseline for either system response to expected threat warheads (vulnerability) or the effectiveness of an offensive weapon against a particular class of targets (lethality). Planning for the Abrams Live-Fire program began late in 1985 and culminated in a series of 48 firings in the period between July 1987 and July 1988.

The Abrams LFT Program was preceded by testing of a number of other systems including the M113 Personnel Carrier and the Bradley Fighting Vehicle (M2/3). As such, considerable experience had been gained both in testing procedures and pre- and post-shot modeling practice. It had become clear to vulnerability workers at the BRL that the extant vulnerability tools were inadequate to describe vehicle damage in a manner consistent with the field-assessment process. To remedy this shortcoming, the BRL/VLD developed a new stochastic point-burst vulnerability code called SQuASH (Stochastic Quantitative Analysis of System Hierarchies),[2,3] in which the following parameters are varied in a Monte Carlo replication of warhead/target encounters: 1] slight variability in hit location, 2] warhead depth-of-penetration, 3] deflection of residual penetrator, 4] spall generation, and 5] individual component-kill assessment.

SQuASH was used to predict 48 shots in the Abrams LF program. Both subjective and statistical tests have been performed in an effort to compare field observations with computer predictions. These comparisons have been made both for component damage as well as Mobility-, Firepower- and Catastrophic-Kill criteria and will be summarized below.

Just as with prior point-burst models and LFT assessments, substantial subjectivity exists in four areas: a] the identification of system-critical components, b] the binning of partially functioning (post-shot) components into kill/no-kill categories, c] the characterization of component interconnectivity *via* the fault tree synthesis and d] the Damage Assessment List (DAL) mapping process (by which M- and F-Kill values are inferred). In order for comparability to exist between field tests and computer simulations, LFT observations must be assessed within the same analytical paradigms of a] through d].

In Reference 3 much of the background of LFT was described and many of the algorithmic details of the SQuASH model were presented. Familiarity with that work may aid in the understanding of these results. In the present paper extensive elucidations of the operational aspects of SQuASH including the means of predicting damage are eschewed; rather, a detailed bottom-up description is given of the vulnerability assessment process. This process begins with the characterization of individual component damage, moves through a system of detailed fault-tree analyses, and finally to the Mobility and Firepower Loss-of-Function (LoF) calculations.

As each step in the process is described, the necessary similitude between model representation and actual field assessment will be emphasized. SQuASH outputs include a series of statistical estimates of warhead penetration performance, individual component probability-of-kill (PK) and component damage-state vectors. Various statistical tests have been applied to the field data *vis-a-vis* the model statistics. We will describe the tests and state our current conclusions concerning them.

---

1. *Live Fire Testing*, National Defense Authorization Act for FY 1987, contained in Chapter 139, Section 2366 of Title 10, United States Code.

2. A. Ozolins, *Stochastic High-Resolution Vulnerability Simulation for Live-Fire Programs*, The Proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association, held at the Naval Ocean Systems Center, San Diego, CA, May 10-12, 1988.

3. Paul H. Deitz and Aivars Ozolins, *Computer Simulations of the Abrams Live-Fire Field testing*, Proceedings of the XXVII Annual Meeting of the Army Operations Research Symposium, 12-13 October, 1988, Ft. Lee, VA; also Ballistic Research Laboratory Memorandum Report BRL-MR-3755, May 1989.

2. COMPONENT DYSFUNCTION

Consider an Armored Fighting Vehicle (AFV) component characterized by a Loss-of-Function (LoF) on the interval (0.0,1.0) where:

$$0.0 \leq \text{LoF} \leq 1.0$$

Zero (0.0) LoF means a component is operating at normal design (pre-shot) specifications. Complete (1.0) LoF means there is no component capability. The notion of a (one-dimensional) LoF is quite natural for describing a component with a single functional characterization such as a pump or electric generator; here the ability to pump fluid or induce current flow can be described on a (single) normalized interval. After being struck by one or more fragments, some classes of components might be operational in a partially functioning state; in the case of a pump, maybe it can supply fluid at half the normal rate so that its LoF would take the value 0.5. For this class of components, the LoF may reflect any value in the interval.

Most classes of components exhibit LoFs which are Bernoulli in nature: that is they either operate fully or not at all. An example of such a component might be a portion of a fire-control system with optical elements. Such a component might be able to absorb fragments up to certain mass velocity combination and suffer no damage until a certain threshold is reached. Then an optical element breaks and the component utterly fails. Such a component would then have only two possible states: 0.0 and 1.0.

We also note that in the case of complex components which must perform multiple functions, the use of a one-dimensional LoF characterization can represent an unrealistic simplification. Such a situation occurs in the description of personnel vulnerability to striking fragments. For people, the term LoF is exchanged for *Level of Incapacitation* (LoI),[4] but the notion is similar. And in such a case, various combinations of limb, torso and head trauma might possibly map to the same LoI and yet reflect entirely different operational capability (e.g. ability to view a battlefield and passively direct fire over a radio *vice* maneuver a vehicle slowly through the use of hand-controls only). Thus the first step in the critical problem of characterizing the potential loss of components is to relate various threat conditions (fragments masses/velocities, blast levels, etc.) to (normalized) LoF.

However for vulnerability analyses such as SQuASH, component characterization must be Bernoulli in nature, i.e. functional/non-functional. Thus in a conceptual sense, a minimum performance threshold for each component must be applied against a LoF following interaction with a threat. If the LoF is sufficiently small that this threshold is at least equaled, the component is considered fully functioning (or alive). If not, it is considered killed.

This process thus yields a crisp binary decision process for each component and can be characterized by a single-pole (SP), single-throw (ST) electrical switch (either closed [alive] or open [nonfunctional]) as in Fig. 1. This concept of the behavior of individual components becomes the basis upon which the analyses of the functionality of systems and sub-systems of the vehicle are based and ultimately the notions of Firepower and Mobility Kills.

To summarize, component dysfunction can be characterized by the following steps:

1. Let a defined threat (fragment, blast wave, etc.) interact with a given component.
2. Characterize any reduction in component capability on a normalized interval as a Loss-of-Function.
3. Bin the (possibly continuous) LoF into crisp Kill/No-Kill binary states.

All point-burst codes accomplish such characterization through the notion of component conditional

4. William Kokinakis and Joseph Sperrazza, *Criteria for Incapacitating Soldiers with Fragments and Flechettes (U)*, Ballistic Research Laboratory Report #1269, January 1965.

Closed Switch → Live Component   Open Switch → Killed Component

Figure 1. All components of an Armored Fighting Vehicle (AFV) start in a working state indicated here as a closed single-pole, single throw (SPST) switch. After interaction with a threat, if the functionality of the component is insufficient to support a minimal capability, the component is considered killed and the switch is opened.

kill probability or component Probability of Kill, given a Hit ($P_{K/H}$). Whether such a process uses fragment mass/velocity/shape-factor/orientation or the notion of lethality†, the component $P_{K/H}$ analysis effectively concatenates all three steps into one.

— CAVEATS RE: COMPONENT DYSFUNCTION —

- Components with complex or multimodal capability may not be well described by a one-dimensional Loss-of-Function.
- The LoF interval may be continuous or discrete.
- The threshold for minimal component operation (to be considered non-killed) is likely to be a function of a specific mission requirement. Thus a component with a fractional LoF might be "alive" in one scenario while "killed" for another.

3. SINGLE-SYSTEM FAULT TREE

The analytical determination of whether a particular system (or sub-system) is functional starts with connecting all of its components together in the form of a series/parallel circuits. These circuits are normally called *fault trees* and an example is given in Fig. 2. Before a shot occurs, all switchs are closed (fully operational). After a live-fire shot, some components may have lost enough capability to be defined as killed (switch open). Three components are killed in this example. The bold line shows the (single) functional path through this system, so this system is considered fully functional.

— CAVEATS RE: FAULT-TREE DEVELOPMENT —

Note well, this process gives rise to a number possible sources of subjectivity both in the analysis and in the field assessment; for example:

- What constitutes a switch (i.e. component)?

  The subjectivity here has two parts, how is the component defined, and is the component critical to the performance of the functions of the system? Only the critical components define the circuit.

- What constitutes a proper subsystem definition?

  Clearly considerable subjectivity enters into this decision process as well.

4. CRITICALITY ANALYSIS FOR AN AFV

A complete *criticality analysis* of an AFV consists of the determination of 1] which components, if lost, *might* result in a reduction of system mobility or firepower capability and 2] the structuring of

† See Reference 3. Section VI., for a discussion of the PKs used in the SQuASH model.

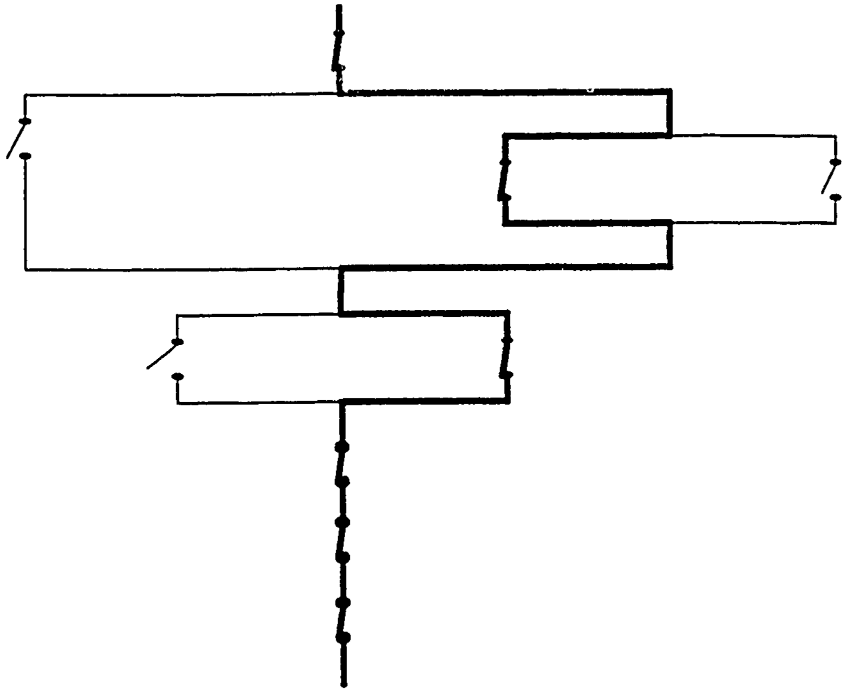

Figure 2. An example of a fault tree used in vulnerability analysis. Parallel components exhibit redundancy; series components do not. An overall system is either fully functional - at least one unbroken path exists from top to bottom, or is killed - no unbroken path exists.

those "critical" components into fault trees as described above. In the case of the Abrams tank, the criticality analysis[5] resulted in the generation of 76 individual fault trees built from approximately 750 critical components.

— CAVEATS RE: CRITICALITY ANALYSIS —

The issues here are:

- What sub-set of AFV components should be classified as critical?
- What n fault trees constitute a proper representation of the AFV?

In addition to the unavoidable subjectivities connected with this process it is further critical that both the live-fire *field-assessment* process *and* the live-fire *modeling* process use the identical fault-tree

5. J. J. Ploskonka, T. M. Muehl, C. J. Dively, *Criticality Analysis of the M1A1 Tank*, Ballistic Research Laboratory Memorandum Report BRL-MR-3671, June 1988.

framework. Otherwise there is no comparability between the two processes and thus no basis for comparing field and predicted results.

5. VULNERABILITY MODELING & LIVE-FIRE TESTING

The analytical estimation of vehicle vulnerability and the assessment of a live-fire test are both characterized by a two-step process:

- **STEP 1:**† Fire a warhead against the target and observe which switches are thrown open by the event.

At this stage, we first predict (or observe) whether the munition breached the armor (perforation) and with what residual energy; then examine the effects of that residual energy on individual components: compile the resultant state of all of the critical components; and decide whether the vehicle suffered total irreparable damage (catastrophic failure or K-kill).

- **STEP 2:** Take the switch states together with the fault-tree logic and process this information in a precisely consistent (but possibly subjective) fashion to infer one or more Measures-of-Effectiveness (MOEs).

For armored fighting vehicles, the MOEs are characterized in terms of loss of the vehicle's primary functions: Mobility (M LoF), Firepower (F LoF), and the greater of the two, Mobility/Firepower (M, F LoF).

— CAVEAT: MODEL VS. FIELD DATA —

- If both the field and modeling processes differ in the precise processing phases of **STEPS 1 & 2**, then comparability is lost.

5.1 Observations re: STEP 1:

If there are n switches (critical components) represented in the criticality process, then there exist 2^n possible unique switch (damage) states. However, LF damage is typically constrained to localized regions of an AFV. Thus only a subset of all critical components are candidates for damage. This reduces significantly the potential number, but from the results of the current model, our simulations typically reveal $\simeq 10^6$ distinct component damage states for a given shot.

If the criticality analysis *and/or* component (binary) kill assessments are inconsistent between the modeling process and live-fire field assessments, then there is no basis for comparability between the test results and model predictions.

5.2 Observations re: STEP 2:

The process of **Step 2** currently involves the Damage Assessment List (DAL).[3] The DAL contains a listing of some 150 major components/AFV systems. If a single major component or system is nonfunctional following a shot, then the M- and F-LoF values are given directly by the DAL. If two or more major components/systems are nonfunctional, LoF values for each are extracted *via* the DAL and survived ‡ to get single M- and F-LoF values. Typically the M- and F-LoF values resulting from **STEP 2**-processing are binned into twenty intervals. Since the damage state dimensionality resulting from **STEP 1** is $\simeq 10^6$, agreement between predicted and field-derived LoFs, ***even if processed by the same methods***, does not imply validation or even support calibration.

† STEP 1 and STEP 2 can be related identically to the mapping processes shown in Fig. 2, Ref. 3. STEP 1 here is the mapping process from Space 1| to Space 2|. STEP 2 here is the mapping process from Space 2| to Space 4|.

‡ The *Survivor Rule* states that the overall LoF of an AFV consisting of n independent systems with individual LoF_n is given by:

$$\mathrm{LoF} = 1 - \Big[(1-\mathrm{LoF}_1)\times(1-\mathrm{LoF}_2)\times\cdots(1-\mathrm{LoF}_n)\Big]$$

6. EXAMPLES OF SQuASH OUTPUT

Figure 3 gives a view of the computer model[3] of the M1A1 looking at the front-left of the vehicle. For this display the armor and main armament have been removed to reveal some of the interior details of the computer description. This modeling effort has produced one of the largest target-description files ever assembled, consisting of over 5000 objects. In addition to this high level of geometric modeling required for the Abrams Live-Fire Program, the stochastic nature of the calculations leads to a complex set of outputs which can best be displayed in the form of summarizing tables and histograms. The samples of these outputs, given in the APPENDIX,[†] exemplify this complexity. Briefly, they show:

- A histogram of residual armor penetration for a 1000 computer replications of a warhead/armor encounter.
- The SQuASH prediction for all critical components killed on at least one of the 1000 replications (ranked by relative frequency).
- Listings of component-damage states for several important classes of critical components. They are ranked according to expected frequency of occurrence.
- Distributions of Mobility, Firepower, and Mobility/Firepower LoF, plus probability of Catastrophic Kill (K-Kill).

7. COMPARISONS: ABRAMS TESTS/SQuASH PREDICTIONS

In the following sections we discuss comparisons between these predictions and the results of the Abrams Live-Fire Tests.[6] In order to keep these discussions unclassified, various detail will necessarily be omitted.

7.1 Perforation

Does the attacking munition succeed in perforating the armor of the vehicle? The answer to this question becomes a first-level input to an estimate of the vulnerability of a tank. Of the 48 shots fired, in 25 tests (52%) the perforation results were predicted *exactly* by SQuASH; that is for each encounter either *all* 1000 replications predicted penetration and penetration was observed in the test or *none* of the 1000 simulations predicted penetration and the field test did not result in penetration. In 42 (88%) of the shots fired, the field outcome occurred in consonance with the larger percentage of computer predictions. Only two (4%) of the shots were not predicted by SQuASH. One shot gave a result not predicted because the round happened to pass through a component that was not modeled in the computer target description. SQuASH failed to predict the perforation outcome of a second shot, a case for which incomplete information was known concerning the performance of that munition.

When input data is adequate, the model seems to predict warhead/armor penetration well.

7.2 Catastrophic Kill

To produce a Catastrophic Kill (K-Kill), the munition must cause damage that is irreparable on the battlefield and renders the vehicle completely incapable of carrying out its mission. In every case SQuASH predicted as the most likely outcome the K-Kill result observed in the field. SQuASH also reminded us that for certain shots the complementary outcome *might have occurred* if the field sample size had been larger.

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† These figures and tables were taken from Ref. 3.

6. C. J. Dively, S. L. Henry, J. H. Suckling, J. H. Smith, W. E. Baker, D. W. Webb and P. H. Deitz, *Abrams Live-Fire Test Program. Comparisons Between SQuASH Predictions and Field Outcomes (U)*, Ballistic Research Laboratory Special Publication, BRL-SP-81, September 1989, SECRET.

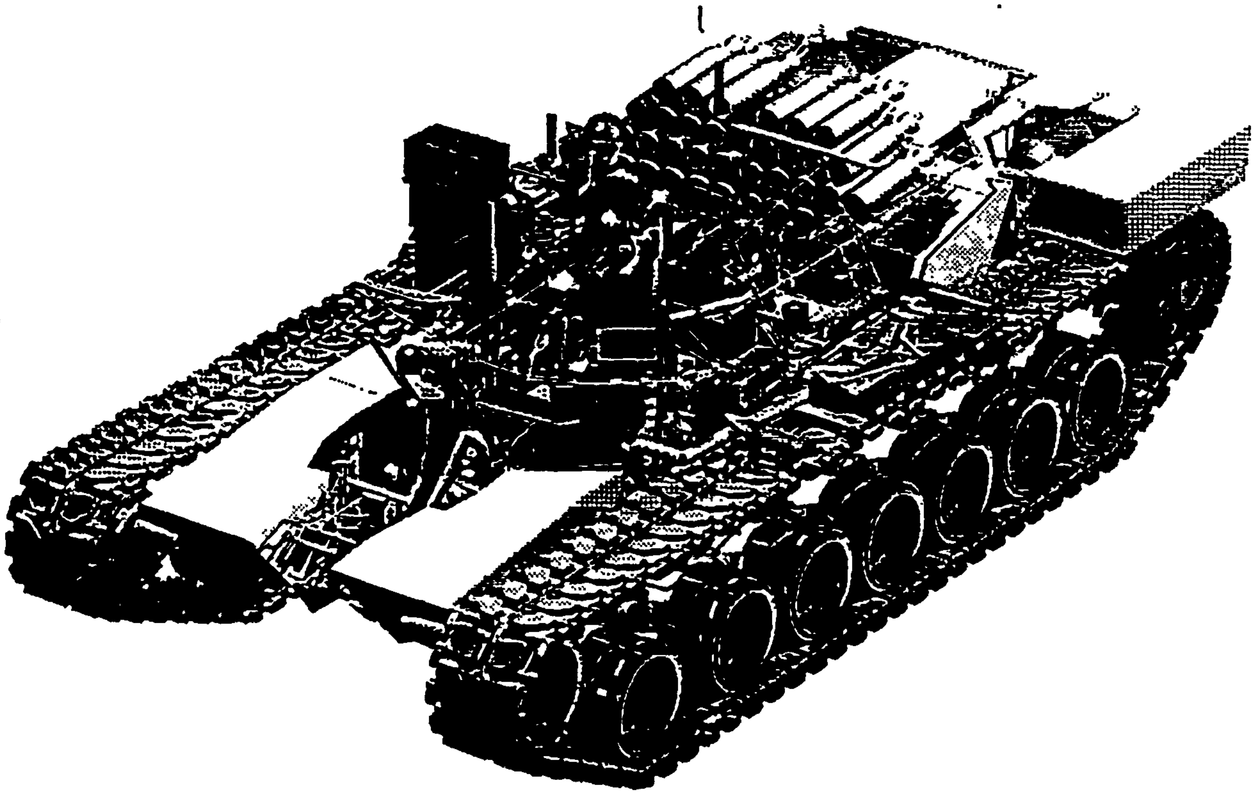

Figure 3. View of the M1A1 produced by the computer description. The armor and main gun have been removed to reveal the level of interior detail. This description contains some 5000 objects of which approximately 750 are critical components.

7.3 Component Kill Assessment

As discussed in the Component Dysfunction Section, all component outcomes are characterized as Bernoulli trials, i.e. functional/nonfunctional. For each field shot (each vector element), a probability of killing the given component is computed equal to the mean of the results of the 1000 SQuASH simulation. Using these 48 probabilities, and assuming statistical independence of the field results, an empirical distribution of the vector is obtained by computing all possible outcomes. The Ordering of Probabilities (OP) Test[7] is used to determine the p-value within that distribution. The p-value reflects the probability of realizing the observed live-fire vector or any vector less likely than the one observed. A p-value of less than 0.05 indicates that the field outcome resulted in a rare vector and causes rejection of the hypothesis that the model output is consistent with the field data.

7.3.1 Initial Individual Component Assessment: Due to the time constraints for analyzing the Live-Fire data, only twenty-six of the components have been analyzed to date for consistency with the model predictions. These components were chosen based upon their relative importance to vehicle Loss-of-Function. Table I gives a listing by system of the components examined.

Table I. Components Evaluated and Grouped by System

Components Evaluated	
Group 1 - Other receiver-transmitter intercom amplifier **Group 2 - Crew** commander gunner loader driver **Group 3 - Electrical** turret networks box hull distribution box hull networks box	**Group 4 - Armament** commander's control panel gunner's primary sight gunner's auxiliary sight commander's gps ext. hydraulic reservoir main hydraulic pump race ring slip ring main gun ammo **Group 5 - Propulsion** driver's master panel alternator power turbine air cleaner electronic control unit transmission/main body fuel

These 26 components over the 48 tests produce 1248 comparisons between the model predictions and the field results. Of these, 969 (78%) were complete matches. A complete match occurs when all 1000 SQuASH outcomes predict the observed field outcome. Thirty-six (3%) of the comparisons resulted in complete mismatches; that is, SQuASH never in its 1000 replications, predicted the component damage observed. The remaining 243 (19%) comparisons were broken down by threat and

7. David W. Webb, *Tests for Consistency of Vulnerability Measures (U)*, Ballistic Research Laboratory Technical Report #3030, August 1989.

component into 34 statistical tests. The OP Test was applied to these groupings. Twenty-two (65%) of these tests accepted the hypothesis that SQuASH predicted the component PK correctly. The remaining 12 (35%) failed the test for consistency.

Combining the complete matches and those components subjected to the OP Test, we get a 90% consistency in predicting individual component PKs for the twenty-six components evaluated.

SQuASH had the most difficulty predicting damage to cables. The twenty-six components evaluated above did not include cables. It is not surprising that SQuASH would have difficulty predicting damage to cables since they have a very small presented area and the shotlines are infinitely thin. An analysis of all components is needed to assess fully SQuASH's ability to predict component damage.

7.3.2 Initial Ranking of Component Discrepancies: Table II summarizes the components having three or more mismatched shots. It was noted that crew members were four of the top five components having significant mismatches. Investigation of the crew data revealed an incompatibility between the field data collected and the data expected by SQuASH. As noted above (**Section 2.**), the SQuASH model performs a binning of all components following a shot into crisp kill/no-kill states. However in the case of the LF personnel data, the original assessments were based on the notion of continuous fractional incapacitation ($0.0 \leq \text{LoF} \leq 1.0$). This incompatibility results in incomparable data for the individual crew components, component damage states, and the Mobility-, Firepower- and Mobility/Firepower Loss-of-Function measures of effectiveness.

Table II. Components Showing Three or More Mismatched Shots of the Twenty-Six Components Investigated

Component	Number of Mismatches	Number of Complete Mismatches
Gunner	10	4
Gunner's Primary Sight	8	6
Driver	7	6
Commander	7	2
Loader	5	3
Main Hydraulic Pump	4	4
Hydraulic Reservoir	4	3
Main Gun	4	1
Turret Networks Box	3	0

7.3.3 Revised Individual Crew Data: In order to make comparisons on how well the SQuASH model predicts crew incapacitation, we must first have comparable scoring between the model and the field results. Since SQuASH expects components to be either functional or nonfunctional after a shot, we asked the organization responsible for personnel vulnerability to convert the fractional incapacitations observed in the field into these categories. An assumption had been made originally that if the loss of function was greater than zero the crew member was totally incapacitated (old bins). The personnel vulnerability experts categorized fractional incapacitation greater than or equal to 0.75 as nonfunctional (new bins). Table III reports the agreement between SQuASH and the field data using both the old bins and the new bins. Although the SQuASH model does agree more with the field data in predicting crew incapacitation, we believe that there are other factors that need to be investigated for all components.

Table III. Improvement in Predicting Crew Based on Binary Field Data

OLD BINS†	NEW BINS‡	RESULTS
54%	59%	Complete match
27%	29%	Most likely outcome predicted by SQuASH
10%	9%	Not most probable outcome, not a rare event (probability ≥ 0.05)
-----	-----	
91%	96%	**Subtotal**
3%	2%	Rare event (probability < 0.05)
7%	2%	Complete mismatch
-----	-----	
9%	4%	**Subtotal**

† If LoF > 0.0, Outcome = Total Incapacitation
‡ If LoF ≥ 0.75, Outcome = Total Incapacitation

7.3.4 Component Damage States: On a given shot. damage of components is not independent. Predicting individual component damage over a set of tests gives no indication of how well we predict component damage state or loss of vehicle functions. All vulnerability measures derived from field tests are a function of the component damage state of the vehicle since that is the field observable. Because of the dependency, the distribution of component damage state must be Monte Carloed using SQuASH.

Again, only a small subset of possible component damage states was evaluated. The 26 individual components were grouped by system categories as shown in Table I (**Crew, Major Electrical, Armament, Propulsion** and **Other**). Each system component damage state empirical distribution was then Monte Carloed from 1000 replicates of SQuASH. The field result from each test and for each of the five system categories ($48 \times 5 = 240$) was then compared with the empirical distribution. If the probability of observing the field result derived from the empirical distribution was less than 5%, the hypothesis that the SQuASH model correctly predicted the component damage state was rejected. This procedure is detailed in the Modified Ordering of Probabilities Test.[8] Since SQuASH only printed the 200 most frequent damage states and occasionally the number of outcomes exceeded this number, there were 14 cases were conclusions could not be drawn; 42 (19%) out of the 226 comparisons resulted in rejection. That is. SQuASH predicted component damage state consistently with the field results in 81% of the cases tested.

7.3.5 Revised Crew Component Damage States: The above analyses on component damage states was based upon the old bins for the crew members. Rebinning the data using the 0.75 incapacitation criteria, we find that SQuASH improves at predicting crew component damage as shown in Table IV. The percentage of rare events (probability of occurrence ≤ 0.05) decreases from 27% to 18% in predicting crew component damage state over all 48 tests.

8. David W. Webb, *A Modification to the Order by Probability (OP) Procedure*, Ballistic Research Laboratory Technical Report, To be Published.

Table IV. Improvement in Predicting Crew Component Damage State

OLD BINS†	NEW BINS‡	OBSERVED FIELD OUTCOME
33%	35%	Predicted on all 1000 SQuASH replications (Complete Match)
27%	31%	Most likely outcome predicted by SQuASH
13%	15%	Not most likely outcome, but not a rare event (probability > 0.05)
-----	-----	
73%	**81%**	**SUBTOTAL**
4%	8%	Rare event (probability ≤ 0.05)
23%	10%	Never predicted in the 1000 SQuASH replications
-----	-----	
27%	**18%**	**SUBTOTAL**

† If LoF > 0.0, Outcome = Total Incapacitation
‡ If LoF ≥ 0.75, Outcome = Total Incapacitation

7.3.6 Analysis of Loss-of-Function: M-, F- and M/F LoFs have not yet been analyzed using the new binning for crew members. Analysis of LoF for the old bins confirmed the SQuASH predictions for Mobility Kills in 41 (85%) of the 48 shots. The field results confirmed the SQuASH predictions for Firepower Kills in 16 (33%) of the 48 shots. Because many different component damage states can map into the same LoF, agreement here is not a sufficient condition to infer consistency of the SQuASH predictions. This is a case where it is possible to get the right answers for the wrong reason. SQuASH is a component-level model and if the component damage state predictions agree with the observed field data it necessarily implies agreement of the LoF measures. That is, agreement of component damage states is both a necessary and sufficient condition to validate the models. LoF analyses are summarized here only to give a complete accounting of the usual vulnerability measures reported.

7.3.7 Secondary Kill Mechanisms: Traditionally, component-level vulnerability models, *in the main*, calculate damage due only to residual main penetrator and behind-armor debris (BAD). These mechanisms are normally termed the *primary-kill* mechanisms. There are well-known conditions underwhich other phenomena such as blast, shock, etc. (often termed *secondary-kill* mechanisms), contribute substantially AFV dysfunction. Due to the time constraints for developing the SQuASH computer model and generating the Abrams pre-shot predictions, only the primary-kill phenomena were modeled.†

In the actual field results, the secondary-kill mechanisms, when observed, were nearly always (there was but a single exception) accompanied by damage due to primary-kill mechanisms. This observation, if borne out by future tests, indicates that, *in the main*, secondary-kill mechanisms, when present, tend to kill (redundantly) components already killed by the primary phenomena. Clearly, future work is needed to weigh the true importance of secondary-kill phenomena.

† Provisions have been made in the SQuASH code to evaluate other damage phenomena as new algorithms and supporting data become available.

8. SUMMARY

This summary reviews the two major themes of the paper: first, the detailed nature of the modeling paradigms utilized in SQuASH and *required* of the LF field assessment procedures for comparability to exist. Second we summarize our efforts to compare statistically model and test data.

8.1 Similitude of Abrams LF Modeling & Field Assessment:

In **Sections 2.-4.** we discussed the construction of the SQuASH model. The chief issues are 1] what constitutes a critical component and how many such items properly characterize an AFV, 2] how should the decision process be constructed leading to the post-shot assessment of Bernoulli kill, no-kill component states, and 3] what is the proper configuration of the fault trees within which the critical components reside?

Without strict adherence to this particular view of the vulnerability world, the field-based assessments cannot be compared properly with the model predictions. We make two related observations: based on the field assessment reports to date we cannot ascertain that indeed those procedures are comparable. We quickly add that we are not inferring that to assess a AFV in a manner inconsistent with our model is wrong, only inconsistent!

It is worth noting that both the description of the model processes given in **Sections 2.-4.** and the manner in which the SQuASH computer model performs its calculations are bottom-up in fashion. However, the way in which the Abrams field assessors performed their investigations was top-down in manner. Following a shot, the assessors generally attempted to operate all major systems in order to flag possible dysfunction. If abnormal function was observed, then further investigations were performed. This procedure could result in missing killed components for which redundant (parallel) backups existed.

8.2 Statistical Comparisons - Field & Simulation Data:

This paper reports our first cycle of comparing LF field and simulation data. The Live-Fire tests result in many measures that can be analyzed to give insight into the modeling process. The investigation of modifications that should be made to SQuASH to improve its predictive capability are complex. Where disagreements are observed in the measures of performance, many sources for the variance exist and must be investigated systematically.

8.2.1 Perforation and Catastrophic Kill: All Live-Fire data has been analyzed for perforation and catastrophic kill. SQuASH predicted perforation consistently in greater than 95% of the field tests. In every case SQuASH predicted as the most likely outcome the catastrophic kill result observed in the field.

8.2.2 Individual Components: In this first set of comparisons, twenty-six of the most important critical components have been analyzed to evaluate SQuASH's ability to predict individual component damage. SQuASH predicted better than 90% of the component damage correctly. Such estimation abilities are important to the Army studies supporting spare parts inventories and repair parameters.

Over *all* components SQuASH had the most difficulty predicting damage to cables. Possible causes include but are not limited to geometric sampling problems related to the very small presented areas, component $P_{K/H}$ characterization, or the fragment densities used for behind-armor debris. This problem and its effect on the component damage state and LoF measures are under investigation.

The ability to predict individual component damage, although *necessary* for agreement between model and test outcome is unfortunately *not sufficient*. System-wide component damage states, summarized below, provide that sufficiency.

8.2.3 Secondary Effects on Crew Members: Secondary kill mechanisms (e.g. blast, shock, vaporifics) as measured on one of the most critical and sensitive of AFV components, crew, do *not* appear significant. In nearly every case where secondary kill phenomena could be observed, component kill had already occurred *via* primary mechanisms. It would appear that the continuing focus of damage characterization should remain on the primary kill mechanisms.

8.2.4 Component Damage State: This measure of performance is both the prime characterization of post-shot damage from which the other measures of performance (e.g. Mobility LoF, Firepower LoF, and Mobility/Firepower LoF) can be inferred as well as the most difficult to predict. The dimensionality of the damage vector can be very high. For conditions where the munition overmatches the armor, we infer typically between one million and 30 million discrete damage-state possibilities at a given location. And yet an actual test gives us only a single field damage state for comparison with all of these possibilities.

We also note that given a consistent mapping of component damage state to the LoF measures, agreement between the field and SQuASH component damage state is both *necessary* and *sufficient* to test consistency of the SQuASH model predictions with the test data.[9]

The limited set of 26 components in this initial analysis of component damage states did not include the component class that SQuASH had the most difficulty predicting, cables. SQuASH currently predicts component damage state correctly in approximately 81% of the cases tested. As more components are analyzed, this number can only decrease. Considering the dimensionality of the problem and the fact that these were the first predictions made using a newly developed stochastic model, 81% agreement is remarkable. Component damage state is under further investigation for improvements to the SQuASH model.

8.2.5 Loss-of-Functions: The LoF measures have been analyzed for all the Live-Fire test results. Although the LoF measures have not yet been analyzed using the new binning for crew incapacitation, the expected improvement is unlikely to significantly change the overall result. Mobility LoF was predicted consistently in 85% of the Live-Fire shots. Only 33% of the predictions for Firepower LoF were consistent with the field data. The dimensionality of the Loss-of-Function space is twenty bins. Many component damage states map into each LoF bin. Considering the dimensionality of this space, we reject the hypothesis that SQuASH predicts Mobility or Firepower LoF consistent with the observed Live-Fire data.

8.3 Current Status & Follow-on Effort:

On balance, considerable progress has been made in the analysis of the Abrams LF data. From this initial analysis our predictive capability is good in some areas. In other instances, for example certain individual component kills, it is clear that we have not done well, but that good, or at least better, agreement can be achieved by modifying certain component PKs. In other areas of the analysis, particularly in the vehicle damage states, we encounter both the damage characterization of greatest importance and the greatest statistical complexity.

We will continue to study carefully the statistics of these damage states. Their number and diversity taken together with the mapping process to various Loss-of-Function metrics lie at the heart of the vulnerability assessment process and the use to which these related Measures-of-Effectiveness (e.g. M LoFs, F LoFs) can be utilized *dependably*. The uses, of course, include the assessment of Live-Fire tests, and the application of vulnerability data to wargames, lethality optimization, vulnerability reduction, and spare-parts estimation.

9. For a discussion of sufficiency conditions for vulnerability model validation, see Michael W. Starks, ***Assessing the Accuracy of Vulnerability Models by Comparison with Vulnerability Experiments***, **Ballistic Research Laboratory Technical Report #3018, July 1989.**

APPENDIX: SAMPLES OF OUTPUTS FROM SQuASH

Figure A-1 gives a histogram showing the distribution of residual-penetrator overmatch. The warhead is unspecified in order to keep these results unclassified. In general, these curves exhibit complex shapes, sometimes with multi-modal distributions.

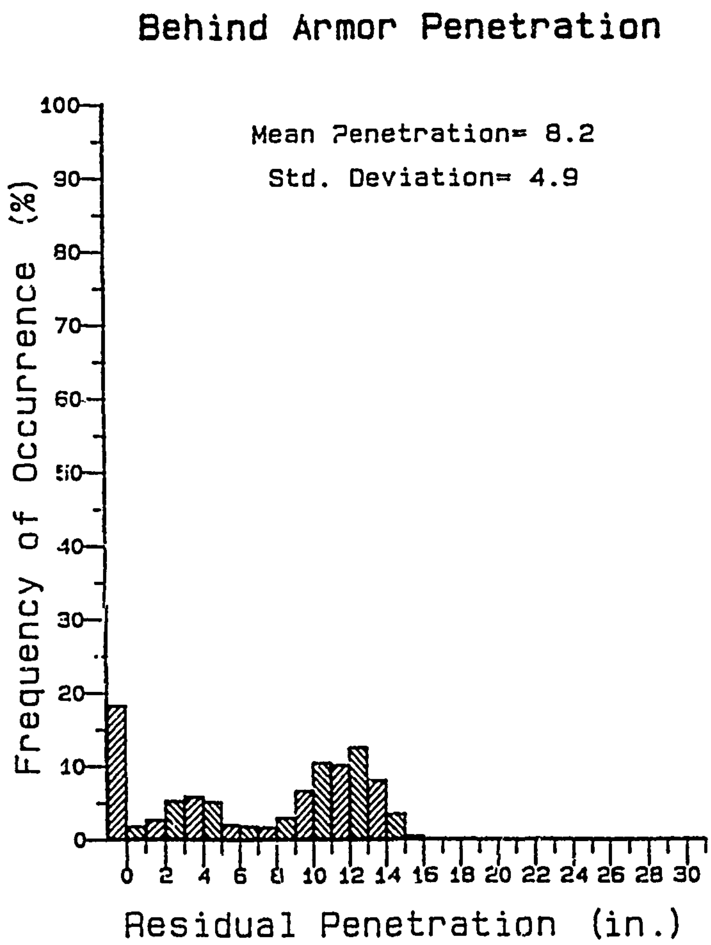

Figure A-1. Histogram of Frequency of Occurrence *vs.* residual penetration. Because nine different shot lines are used (typically encountering different armor types) together with variable warhead performance, different levels of overmatch are derived.

This is a natural consequence of the randomness of the overmatch together with the grid ray data derived over nine sample rays. Even though the rays are separated nominally by three inches, different combinations of armor are often encountered. The difference in effective protection levels can lead to significantly different residual magnitudes.

For one sample calculation over the course of 1000 code replications, some 60 critical components were assessed to have been killed at least once. Table A-I lists these components. The remainder of the figures and tables in this appendix were taken from Ref. 3.

Table A-I. Listing of all components killed in at least one of 1000 replications of the SQuASH vulnerability model. The columns give the component identification, the total probability of kill, the probability of kill from the jet alone, and the probability of kill from fragments alone, respectively.

Component	Relative Frequency of Damage		
	P_t	P_j	P_f
commander	0.399	0.000	0.399
gunner	0.995	0.683	0.594
loader	0.301	0.000	0.301
cable 1w103-9	0.018	0.000	0.018
cable 1w101-9	0.011	0.000	0.011
cable 1w104	0.008	0.000	0.008
cable 1w104	0.137	0.000	0.137
cable 1w105-9 main branch	0.008	0.000	0.008
cable 1w107-9	0.007	0.000	0.007
cable 1w108-9 to main gun	0.034	0.000	0.034
cable 1w200-9	0.552	0.000	0.552
cable 1w201-9	0.011	0.000	0.011
cable 1w202-9 main branch	0.017	0.000	0.017
cable 1w203-9	0.012	0.000	0.012
cable 1w208-9	0.309	0.000	0.309
cable 1w209-9	0.216	0.000	0.216
cable 1w210-9	0.337	0.000	0.337
cable 1w301	0.158	0.000	0.158
cable 1w304	0.039	0.000	0.039
cable 1w306	0.017	0.000	0.017
cable 1w309	0.070	0.000	0.070
cable 1w310	0.027	0.000	0.027
cable 1w311	0.008	0.000	0.008
cable 1w312	0.012	0.000	0.012
cable 1w316	0.035	0.000	0.035
cable 2w105-9	0.044	0.000	0.044
cable 2w107-9	0.009	0.000	0.009
cable 2w108	0.006	0.000	0.006
cable 2w112	0.002	0.000	0.002
cable 2w154-2w155	0.012	0.000	0.012
hull distribution box	0.003	0.000	0.003
hull networks box	0.012	0.000	0.012
turret networks box	0.046	0.000	0.046
gunner's primary sight	0.025	0.000	0.025
commander's gps extension	0.107	0.000	0.107
thermal image control unit	0.208	0.000	0.208
thermal receiver	0.001	0.000	0.001
intercom amplifier	0.024	0.000	0.024
gunner's intercom control box	0.104	0.000	0.104
loader's intercom control box	0.018	0.000	0.018
cable 2w117-9	0.003	0.000	0.003
h.line aux pump to filter mani	0.003	0.000	0.003
filter manifold	0.013	0.000	0.013
h.lines filter manifold to HDM	0.018	0.000	0.018
h.lines filter manifold to HDM	0.007	0.000	0.007
h.lines TDM to azimuth servo	0.003	0.000	0.003
h.lines TDM to azimuth servo	0.011	0.000	0.011
azimuth gearbox	0.004	0.000	0.004
manual azimuth gearbox	0.004	0.000	0.004
manual azimuth gearbox	0.008	0.000	0.008
manual elevation pump	0.015	0.000	0.015
manual elevation pump	0.005	0.000	0.005
gunner's control handle	0.016	0.000	0.016
commander's control handle	0.073	0.000	0.073
race ring	0.013	0.000	0.013
h.line TDM to man elev pump cd	0.004	0.000	0.004
h.line check valve to HDM bypa	0.020	0.000	0.020
coaxial ready ammo box	0.052	0.000	0.052
azimuth gearbox - cws	0.022	0.000	0.022
commander's vision block #3	0.003	0.000	0.003
commander's vision block #2	0.005	0.000	0.005
commander's vision block #1	0.004	0.000	0.004
loader's sight	0.017	0.000	0.017
f.line right bow to manifold	0.001	0.000	0.001

P_t - [illegible]l Damage due to all mechanisms
P_j [illegible]ge due to jet
P_f - [illegible]ge due to fragments

The next two tables show how SQuASH output departs radically beyond other point-burst models. Here two classes of components are examined separately by category. This procedure has been adopted because of the great difficulty in interpreting the results of damage states across the complete vehicle. Table A-II lists the category of **CREW**. For this group, the calculated damage states apply to the personnel located in the turret-basket area. The damage states derived from the 1000 replications were sorted together and then ranked from the most to the least likely in occurrence. Table A-II shows that the most likely crew casualty state is for the commander and loader *not* to be incapacitated and for the gunner *to be* incapacitated. That outcome occurred 461 of the 1000 replications, for a net probability of 46%. The next most likely crew casualty state is for the commander and gunner to be incapacitated but not the loader. The likelihood of this outcome is assessed at 24%. For this component subset. SQuASH predicted probable outcomes for only six of the eight possible combinations of commander. gunner. and loader.

Table A-II. Damage states from the SQuASH simulation for the subset *CREW*. Open squares (□) indicate no component kill. Bullets (•) indicate a component kill. The component numbers correspond to the listing below the table. The relative probability of each damage state is given in descending order of likelihood (column state**). The cumulative sum is given in the last column** (sum)**.**

Group: **CREW**
Damage States, sorted by likelihood

Damage States			**Relative Occurrence**	
Component Number 1	2	3	state	sum
□	•	□	0.461	0.461
•	•	□	0.237	0.698
•	•	•	0.192	0.890
□	•	•	0.103	0.993
□	□	□	0.005	0.998
•	□	□	0.002	1.000

□ - component undamaged
• - component damaged

Number	Component
1	*commander*
2	*gunner*
3	*loader*

The component damage states for **ARMAMENT**, shown in Table A-III, reveal the greatest complexity in damage states. This is probably to be expected since nearly half of all the critical components killed during the 1000 replications were part of this group. As seen in other groupings, the most likely damage state assessed for the 29 components in **ARMAMENT** is no damage, this for 28% of the outcomes. The most likely state exhibiting damage occurred for five components (numbers 6, 10-12, 15) on 78 of the 1000 replications for a 7.8% probability. From here on, the 29 components are involved in a slow convergence to the 99th percentile (sum) at the 223rd damage state!

The final stages of calculation of vulnerability involve the various categories of kill. First, catastrophic kill represents the complete loss of the system, which generally occurs in encounters with large-caliber ammunition (warhead and/or propellant) or fuel. The probability of this event is shown in Fig. A-2c. For this particular shot, the probability of a catastrophic event is assessed as zero. Note

Table A-III. Component damage states from the SQuASH simulation for the subset *ARMAMENT*. Format and labeling follow the procedure used in Table A-II.

Group: ARMAMENT
Damage States, sorted by likelihood

Damage States																													Relative Occurrence	
Component Number																														
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	state	sum
□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.275	0.275
□	□	□	□	□	•	□	□	□	•	•	•	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.078	0.353
□	□	□	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.077	0.430
□	•	□	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.060	0.490
□	□	□	□	□	•	□	□	□	•	□	•	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.039	0.529
□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.026	0.555
□	□	□	□	□	•	□	□	□	•	•	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.023	0.578
□	□	□	□	□	•	□	□	□	•	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.013	0.591
□	□	□	□	□	□	□	□	□	□	□	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.011	0.602
□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	•	□	□	□	□	□	□	0.010	0.612
□	□	□	□	□	•	□	□	□	□	□	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.010	0.622
□	□	□	□	□	□	□	□	□	•	•	•	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.010	0.632
□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	•	□	□	0.009	0.641
□	•	□	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	•	□	□	□	□	□	□	0.008	0.649
□	□	□	□	□	•	□	□	□	□	□	•	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.007	0.656
															⋮														⋮	⋮
□	□	□	□	□	•	□	□	□	•	•	•	□	□	•	□	□	□	□	□	•	•	•	□	□	□	□	□	□	0.001	0.998
□	□	□	□	□	•	□	□	•	□	□	□	□	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.001	0.999
□	□	□	□	□	•	•	□	□	•	•	•	□	•	•	□	□	□	□	□	□	□	□	□	□	□	□	□	□	0.001	1.000

Converges at the 223rd state

□ - component undamaged
• - component damaged

Number	Component	Number	Component
1	*cable 1w104*	16	*filter manifold*
2	*cable 1w104*	17	*h.lines filter manifold to HDM*
3	*cable 1w105-9 main branch*	18	*h.lines filter manifold to HDM*
4	*cable 1w107-9*	19	*h.lines TDM to azimuth servo*
5	*cable 1w108-9 to main gun*	20	*manual azimuth gearbox*
6	*cable 1w200-9*	21	*manual elevation pump*
7	*cable 1w201-9*	22	*gunner's control handle*
8	*cable 1w202-9 main branch*	23	*commander's control handle*
9	*cable 1w203-9*	24	*race ring*
10	*cable 1w208-9*	25	*h.line check valve to HDM bypa*
11	*cable 1w209-9*	26	*coazial ready ammo box*
12	*cable 1w210-9*	27	*azimuth gearbox - cws*
13	*gunner's primary sight*	28	*commander's vision block #2*
14	*commander's gps extension*	29	*loader's sight*
15	*thermal image control unit*		

that the histogram associated with K-Kill can be populated only in the first and last bins. In other words, catastrophic failure either occurs or it does not; the outcome is either zero or one.

The other kill categories are assessed by mapping each of the thousand damage states *via* the SDAL over to the appropriate M- and F-Kill values. The category labeled M/F (read M OR F), by long-standing agreement with the TRADOC community, represents *the larger* of the two values. *It is not the* OR *of the logical (Boolean) operation.*

We examine the M-Kill plot in Fig. A-2a. Here we find the most likely outcome is for about 0.57 Mobility Loss-of-Function (M-LoF), assessed at about 30% probability. However the distribution is extremely broad with approximately 18% of the outcomes near the 0.0 bin. The expected M-LoF outcome is 0.36, inspection of the histogram shows that there are approximately 26% of the outcomes near this value. However the distribution is broad, and there is a significant number of occurrences away from the mean. The corresponding results for Firepower LoF are given in Fig. A-2b. In this histogram, the mean LoF occurs in a bin with a low population. There is also a significant probability ($\sim$ 18%) that the F-LoF will be zero. The M/F-LoF histogram is given in Fig. A-2d. The M/F value, by definition, is the larger of the M and F-LoFs on a shot-by-shot basis. The F-LoF tends to dominate in this case.

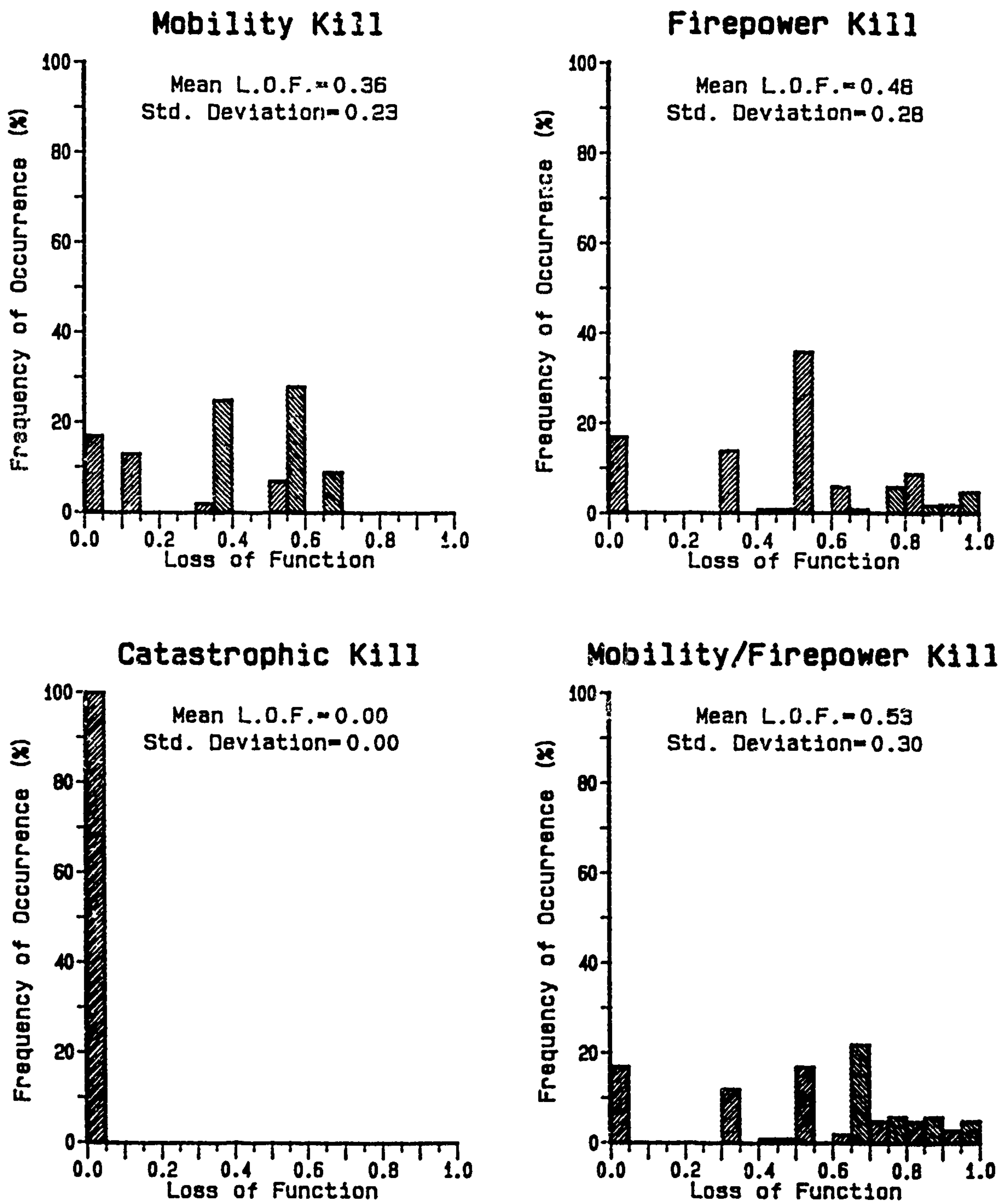

Figure A-2. Histograms of various kill categories derived from the SQuASH simulation. The Mobility Kill Loss-of-Function (LOF) is shown in a), the Firepower Kill in b), the Catastrophic Kill in c), and the Mobility/Firepower Kill in d). The means (expected values) and standard deviations are given for each plot, but are considered relatively immaterial for these non-parametric (i.e. non-gaussian) statistics.

#127

TITLE: An Independent Evaluator's View of Operational Availability (Ao)

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ABSTRACT:

Operational availability (Ao) is a single number which tells how much of the time a materiel system is able to operate in a specified or desired manner in an environment typical of that expected for real Army operations. Intuitively, this number would seem to be very important because it should provide a clear indication of how dependable a system would be in combat. Prior to a production decision (Milestone III), great emphasis is placed on specifying a value for Ao based on the proposed operational mode summary/mission profile for the system. Even a relatively inexperienced independent evaluator quickly notes some facts about Ao which hold true for virtually all systems.

A. The specified value for Ao is always quite large, such as 0.98.
B. The value of Ao determined from operational test data on the system never meets the specified value, and seldom even comes close to it.
C. Often, Ao is not computed or is incorrectly computed because of data shortfalls in the operational test.
D. The decision body ignores Ao and buys the system anyway.

Experience shows that decision makers either do not understand what Ao is telling them, or do not put much faith in it as an indicator of system performance. At least part of this is due to inherent limitations in the way Ao is defined and the way the formula for its computation is stated and explained. Part of the problem also lies in the "logistics dilemma", where the logistic support structure cannot be fully evaluated until the system is fully fielded to the Army--after Milestone III. This paper will discuss these and other problems which limit the usefulness of Ao, as well as describe how a TRADOC-developed independent evaluation methodology has been used to partly compensate for the problem.

No Paper Provided

Stress Measurement in Operational and Experimental Settings

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The effects of stress on human performance have received extensive attention (Hockey, 1986). Stress-induced performance decrements have been demonstrated in soldiers performing combat-relevant tasks (Torre and Kramer, 1966). The present HEL Stress Research Program (Hudgens, Torre, Chatterton, Wansack, Fatkin, and DeLeon-Jones, 1986), a combination of in-house and contract efforts, is presently studying the links between psychological and physiological stress reactions and performance in a variety of settings. This program is well along in its effort to develop a psychological and physiological metric of stress that can be used to compare stress levels across situations. The goals of our stress research program are to develop a metric that would allow us to determine, in a relative sense, how stressed soldiers become under a variety of experimental and operational conditions, and to develop acceptable means of testing soldier-operated systems under stressful conditions. The Human Engineering Laboratory, working with Northwestern University, has made considerable progress in developing the psychological and endocrinological measurement tools needed to implement this metric.

To date, studies conducted under this program have included a variety of situations, including waiting while one's spouse has outpatient surgery, waiting while one's spouse has major surgery, taking an important medical school oral examination, taking a major written examination in medical school (Hudgens, Chatterton, Torre, Slager, Fatkin, Keith, Rebar, DeLeon-Jones, and King, 1989), firing in an interunit competitive marksmanship situation while being observed by one's fellow soldiers (Torre, Wansack, Hudgens, King, Fatkin, Mazurczak, and Myers, in preparation), and soldiers fighting the 1988 Yellowstone National Park fires. We are, of course, very interested in the opportunity to study new, and potentially highly stressful situations in order to evaluate their effects on performance.

Salvo Stress Study

In the Salvo Stress Study, we evaluated the effectiveness of competition as stress in soldier-equipment testing, and used the metric to assess the level of stress experienced. Subjects in this field experiment were 60 volunteer infantrymen. On the two competition weeks, 10 soldiers from each of two divisions participated, on the control week, 20 soldiers from one division served as subjects. During the competition weeks, soldiers competed as teams for a plaque in full view of their comrades and competitors, their performance was videotaped, and their scores were announced over a public address system and were posted on a large scoreboard placed next to the viewing stands. On the control weeks, all of these stressors were removed. Physiological measures collected included an extensive collection of hormones which have been shown to be responsive to stress in our other studies. This work was an attempt to extend past research, to include our stress program (Hudgens, Torre, Chatterton, Wansack, Fatkin, and DeLeon-Jones, 1986), by studying soldiers accomplishing military tasks when exposed to the real but noninjurious stress of competition. The stress was produced by having soldiers perform a military task, firing a rifle, in a competitive situation which reflected on their unit and on themselves. Other task-induced stressors included random presentation of targets by range, exposure time, and number of targets up at a time.

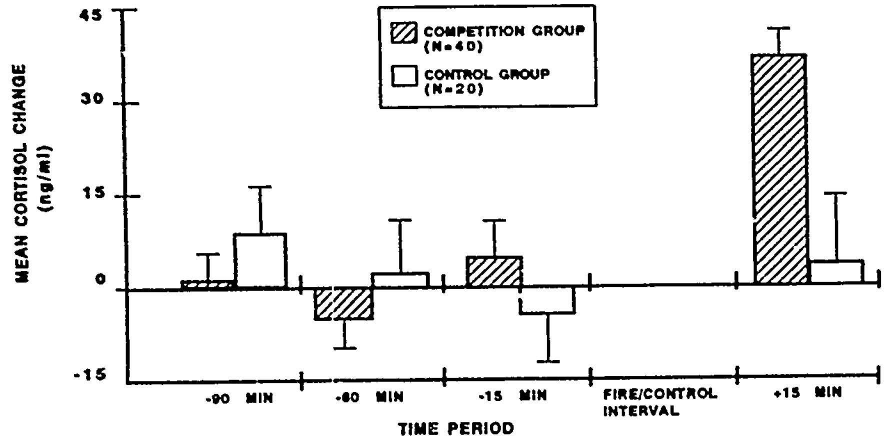
Stress Evaluation

One of the primary objectives of this study was to determine if competition could be used to generate a significant level of stress in a systems test such as that included in this study. To determine whether a significant level of stress was generated and to determine the relative degree of stress generated, batteries of psychological trait and state measures as well as physiological state measures were employed. Evaluations were made by reference to results reported for the various measures in the literature and by reference to results obtained in a recent series of stress studies using these same measures as a part of the HEL Stress Program.

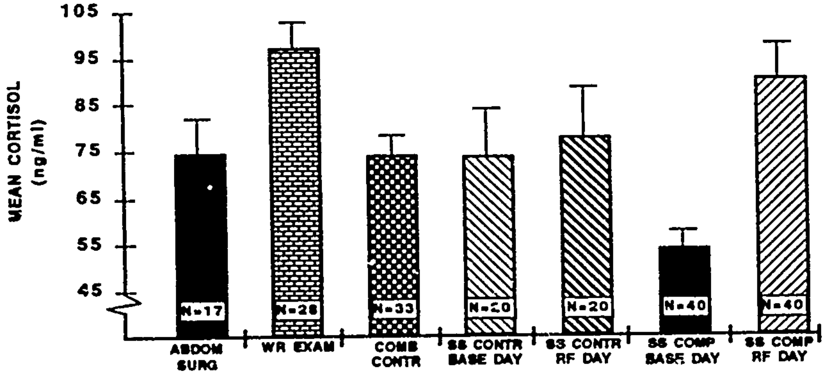
Comparison of the Competition and Control Groups indicated that the Competition Group showed consistently and significantly greater stress-related response changes on endocrine measures as a function of firing under competition than did the Control Group. These data for cortisol (CORT) and testosterone (TEST) are shown in the two left panels of Figure 1. Note that the stress responses, elevated cortisol and suppressed testosterone are apparent only after the stress event. Comparison of the endocrine data obtained for the Competition Group 15 minutes after firing for record in competition with the endocrine data obtained at the same relative time point in the Northwestern University stress protocols (the right two panels of Figure 1), revealed that the Competition Group had a response profile very similar to that obtained for medical students when taking an important written examination (WR EXAM), a moderately stressful situation. The Control Group, on the other hand, had a profile more characteristic of other, relatively non-stressful, control conditions. Both groups in the present study showed relatively high levels of testosterone, even higher levels than the group of medical students taking an examination. At this time, we can only hypothesize that the relative level of testosterone observed across the groups might relate to differences in the performance requirements of the various situations. That is, testosterone appears to have increased as the performance demands increased across the situations.

The psychological data strongly reinforce the conclusions reached based on the physiological data. These data are shown in Figure 2. Consistent with the interpretation that the Competition Group was under more stress than the Control Group, the Competition Group subjects expressed significantly greater state anxiety than Control subjects both 15 minutes before, on the Multiple Affect Adjective Check List - Revised (MAACL), and after firing on Record-Fire Day. Additionally, the Competition Group subjects expressed greater hostility 15 minutes after

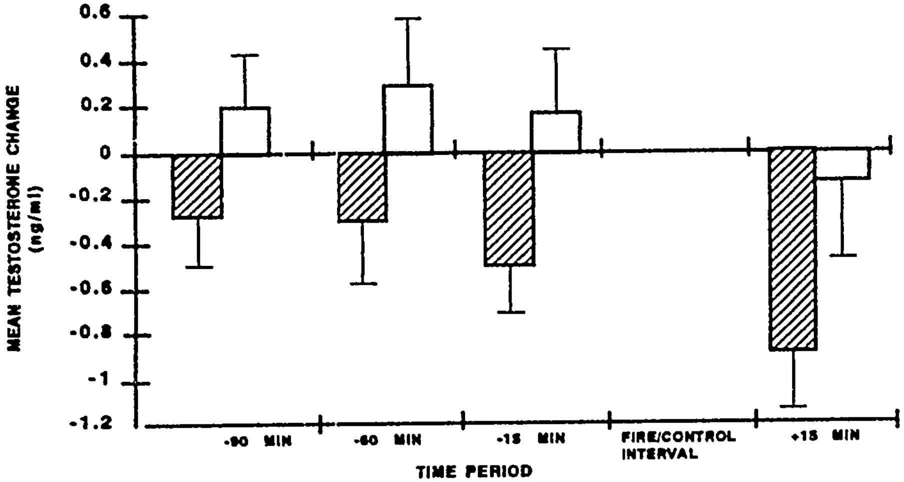
FIGURE 1



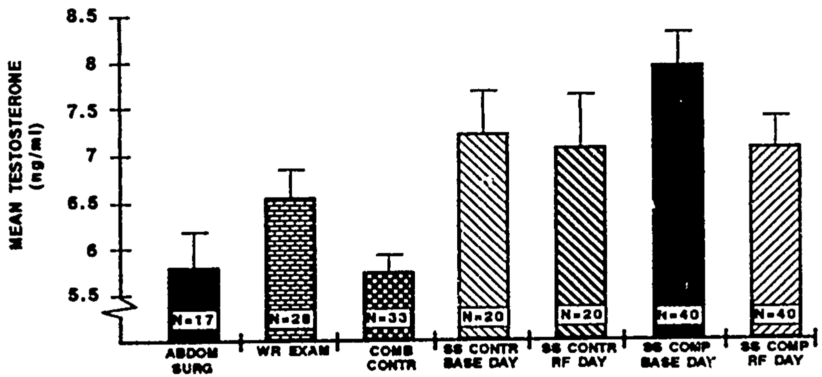
Mean (+standard error) change in levels of cortisol for Competition and Control Groups for the four sampling times common to Baseline and Record-Fire Days. (Change= Record-Fire level - Baseline level.)



Comparison of 15-min post-stress cortisol levels (mean+standard error) for Competition and Control Groups on Baseline and Record-Fire Days with those for subjects in the conditions: 1) spouse having serious abdominal surgery 2) taking an important medical school written exam; or 3) control conditions for 1 & 2 (combined).

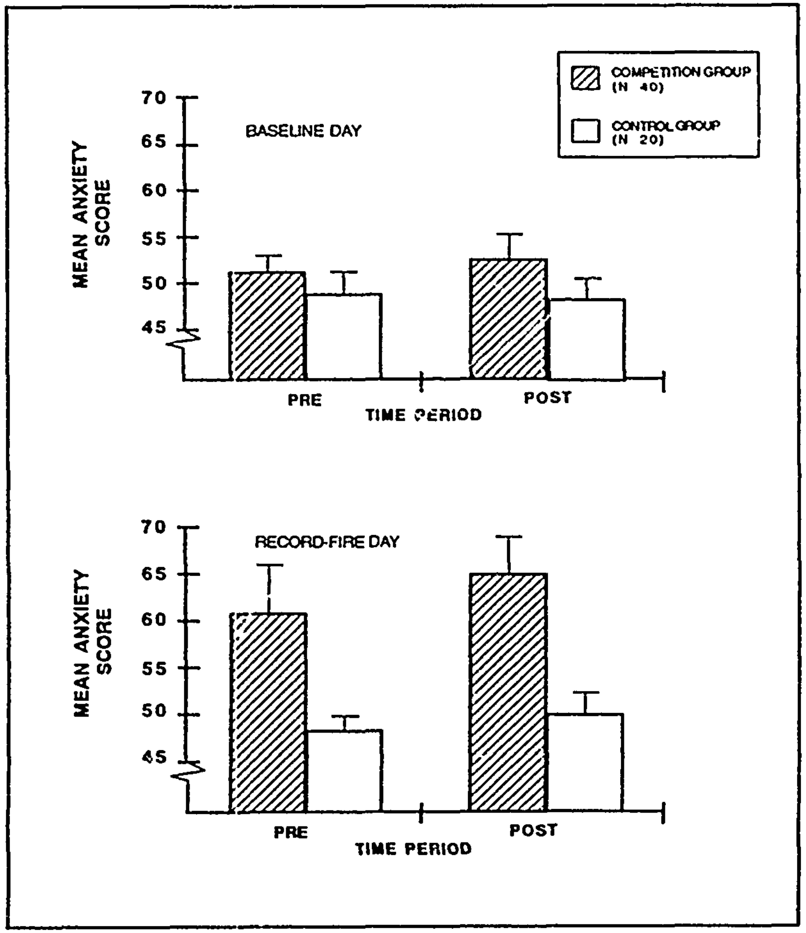


Mean (+standard error) change in levels of testosterone for Competition and Control Groups for the four sampling times common to Baseline and Record-Fire Days. (Change= Record-Fire level - Control level.)

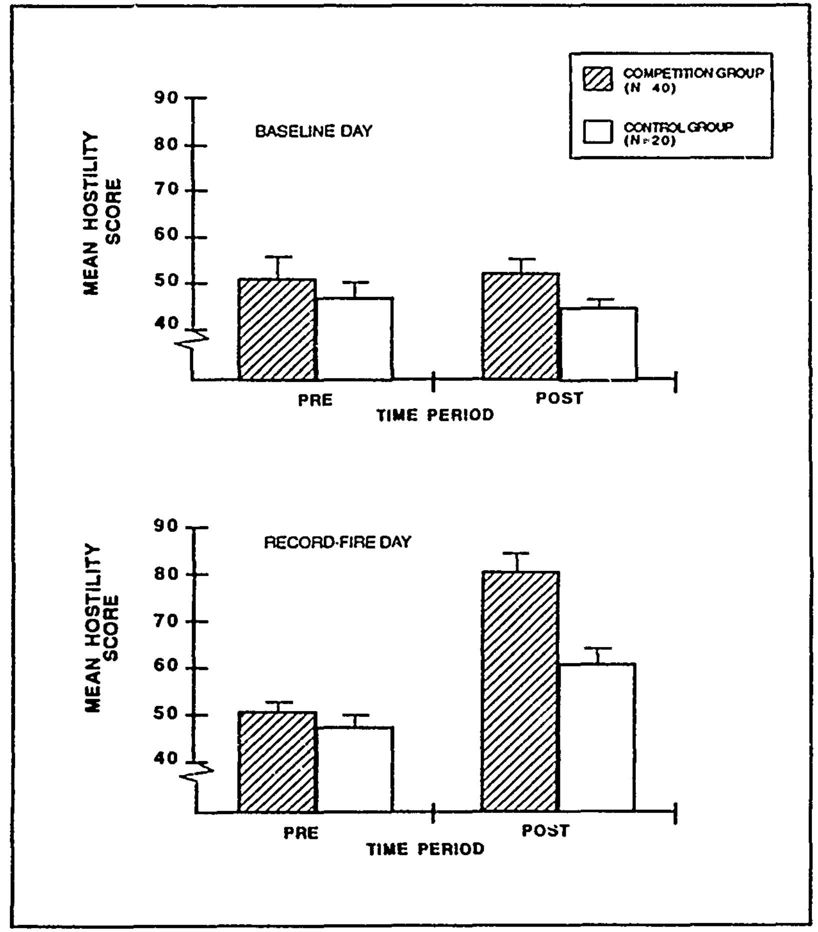


Comparison of 15-min post-stress testosterone levels (mean+standard error) for Competition and Control Groups on Baseline and Record-Fire Days with those for subjects in the condititions: 1) spouse having serious abdominal surgery; 2) taking an important medical school exam; or 3) control conditions for 1 & 2 (combined).

FIGURE 2



Mean (+standard error) pre- and post-MAACL-R Anxiety scores for the Competition and Control groups on Baseline Day and on Record-Fire Day.



Mean (+standard error) pre- and post-MAACL-R Hostility scores for the Competition and Control groups on Baseline Day and on Record-Fire Day.

firing. These findings appear to reflect greater dissatisfaction with personal performance under competitive conditions. The anxiety expressed by the Competition Group appears most comparable to that of the group of medical students taking a written exam. This finding parallels the comparisons for the cortisol data and supports the interpretation that a moderate level of stress was experienced by the Competition Group. Additionally, the comparative post-stress hostility ratings for the Competition and Control Groups reveal a pattern which is similar, across groups from the various studies, to the pattern of comparative testosterone levels. As was the case for testosterone, the magnitude of response appears to have increased as the performance demands increased across situations.

Performance Correlates

The performance correlates are summarized in Table 1. Two of the demographic measures taken were predictive of performance. The longer the soldiers reported being in the Army, the better they performed in the burst mode; and the more different weapons they were currently qualified on, the better their performance in the semi-automatic mode. With regard to the hormone data, it appears that different predictive relationships existed depending on whether the subjects performed under competitive as opposed to noncompetitive conditions. For the Control Group, lower prolactin levels early in the morning of Baseline Day were predictive of better performance in the semi-automatic mode. For the Competition Group, lower testosterone levels on Baseline Day and early on Record Fire Day were predictive of better performance in the burst mode. Three personality (trait) measures were predictive of performance. Lower scores on the MAACL Depression, Hostility, and Negative Affect Trait subscales were predictive of better performance.

This study demonstrated that competition can be used to generate stress in test subjects. The level of stress generated does not appear to have been sufficiently intense to have adversely affected the performance of the Competition Group relative to controls. Since future applications of a method for generating stress in systems evaluations will require a level of stress considered comparable to combat stress levels, research on methods of generating a higher level of stress will have to continue. The results of this study suggest that competition might serve as one component of a methodology which might also include multiple stressors or acute plus chronic stressors as it appears combat stress does. These findings also suggest that, in evaluating a potentially stressful circumstance, it is important to consider both the objective (experimenter designated) and the subjective (subject experienced) aspects of the situation (Hobfoll, 1989).

Yellowstone Stress Evaluation

In September 1988, the Concepts Analysis Agency (CAA) requested participation in an effort to evaluate the level of stress experienced by the soldiers who had fought the fires at Yellowstone National Park. The ultimate goal of this effort is to provide improved human factors data for use in combat models by assessing the degree to which the stress of fighting a fire resembles the stress of fighting a human

TABLE 1

Significant Performance Predictors for Salvo Stress Study

Predictor Category	Group(s)	Performance: SemiAutomatic Mode	Performance: Burst Mode
Experience	Combined (Competition & Control)	Current Weapon Qualifications r = +0.26*	Length of Service r = +0.33*
Trait Measures	Combined	MAACL-R Depression r = -0.31* Hostility r = -0.29* Negative Affect r = -0.36**	
Hormones	Control	Baseline Day Prolactin -90 min/r = -0.48* -60 min/r = -0.53*	
	Competition		Baseline Day Testosterone -60 min/r = -0.39* -15 min/r = -0.34* +15 min/r = -0.37* Record-Fire Day Testosterone -90 min/r = -0.34*

* $p < .05$
** $p < .01$

enemy. The evaluation team, which included personnel from CAA, Human Engineering Laboratory, Walter Reed Army Institute of Research, and Army Research Institute, felt that these fires afforded an outstanding opportunity to study stress reactions and to collect human factors data in a real operational setting that shares with combat the elements of personal danger and uncertainty. We developed a questionnaire that was given to the soldiers to evaluate their stress levels during the fire fighting.

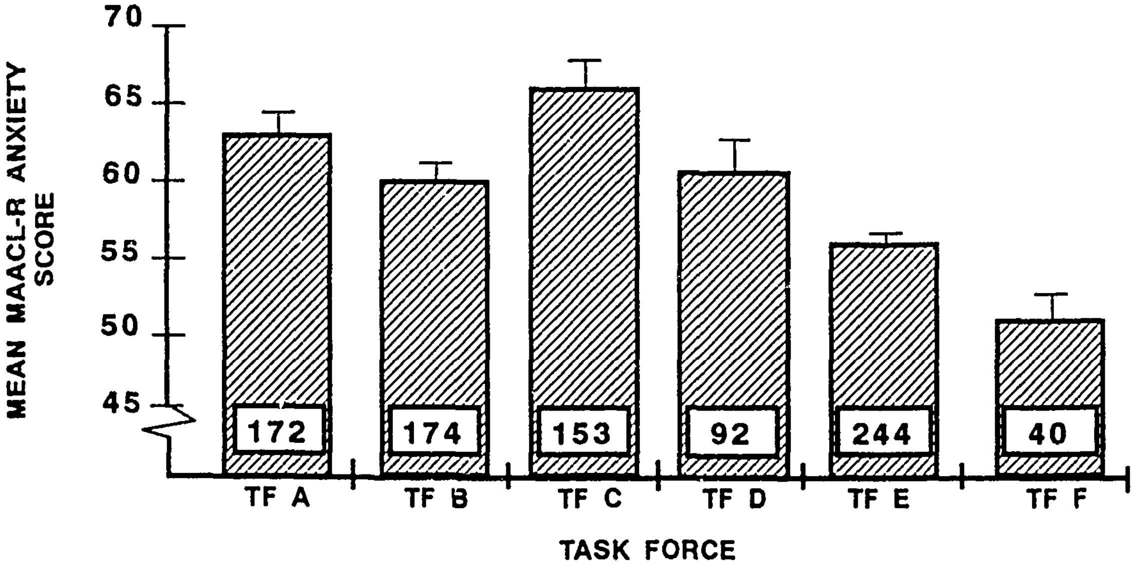
The subjects were 1100 soldiers, noncommissioned officers, warrant officers, and officers of the 9th Infantry Division (Motorized), Fort Lewis, Washington, and supporting units who participated in or supported the 1988 fire fighting operation at Yellowstone National Park. All subjects participated in the study voluntarily. The survey used for this study contained adjective checklists (the Multiple Affect Adjective Check List-Revised to describe how they felt when filling out the survey and when actually fighting the fire. Although the survey was customized for this application, nearly all of the scales had been used in other studies that comprise our stress program to permit us to use the psychological portions of our stress metric which is in the early stages of development to assess the stressfulness of the Yellowstone fire fighting experience. The surveys were administered to soldiers in either company or battalion groupings at Yellowstone National Park, Bozeman, Montana, and Fort Lewis, Washington after they had completed fire fighting. The soldiers were provided with the survey and were briefed about the purpose and content of the instrument.

Results and Discussion

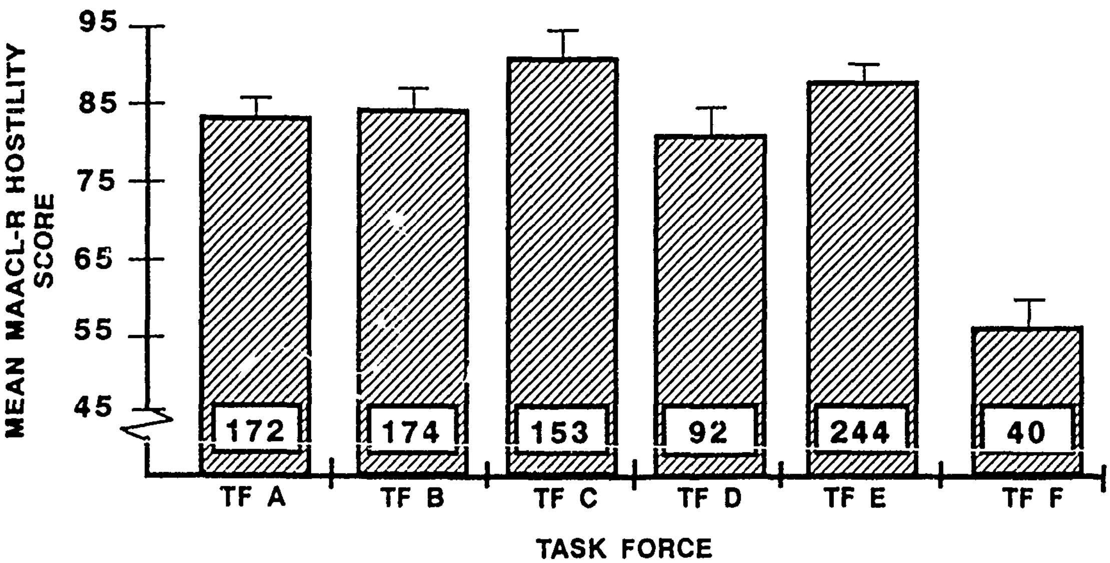
The present paper presents data from 1100 soldiers in the context of data obtained in the other HEL Stress Program studies. Thus, we will tie the level of stress experienced by these soldiers to that experienced by the subjects in the other studies. The data presented in the figures that follow are displayed in a mean plus one standard error format.

The MAACL-R scores for Anxiety and Hostility (Figure 3), broken down by Task Force (TF) reveal that TFs C and F, although generally at opposite ends of the response spectra, are clearly distinguishable from the other TFs on the measures. These data are consistent with the number of days spent in high stress fire fighting duties for each task force, which were 10 for TF A, 0 for TF B, 13 for TF C, 6 for TF D, 8 for TF E, and 0 for TF F. Thus, the measures of stress have been shown to be sensitive to variations in stress levels in this field situation, and to naturally and experimentally induced stress (see Figure 4). The present results are less useful than might otherwise be the case due to lack of true baseline and objective performance measures and the time delay in obtaining access to the soldiers, shortcomings which we plan to correct in subsequent efforts.

FIGURE 3

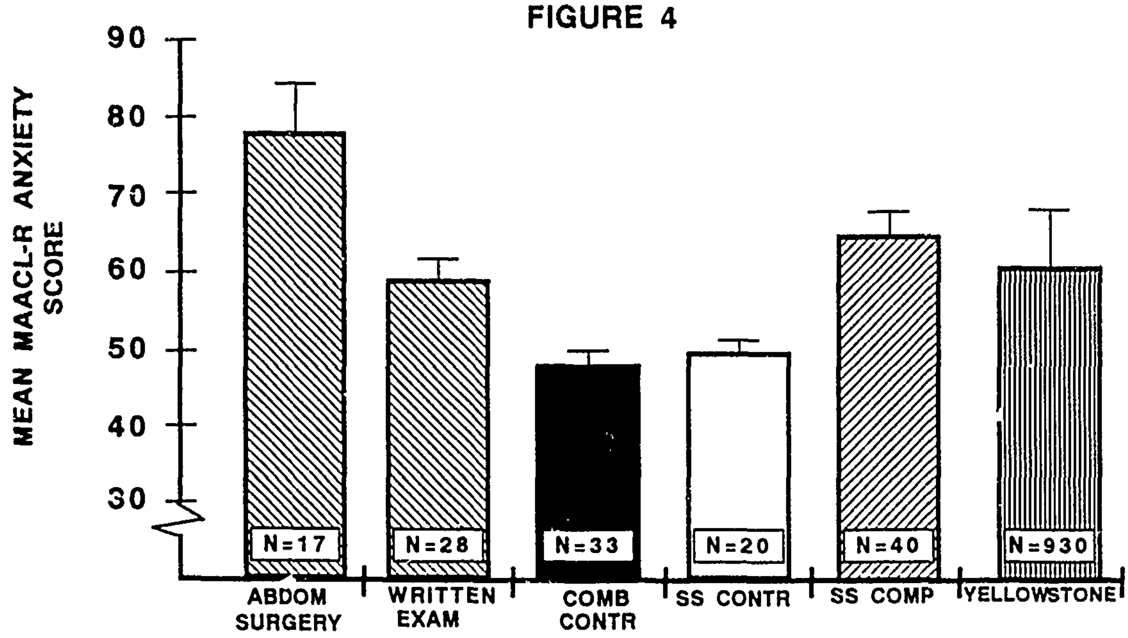


Mean (+standard error) post-stress MAACL-R Anxiety scores for each fire-fighting Task Force (TF).

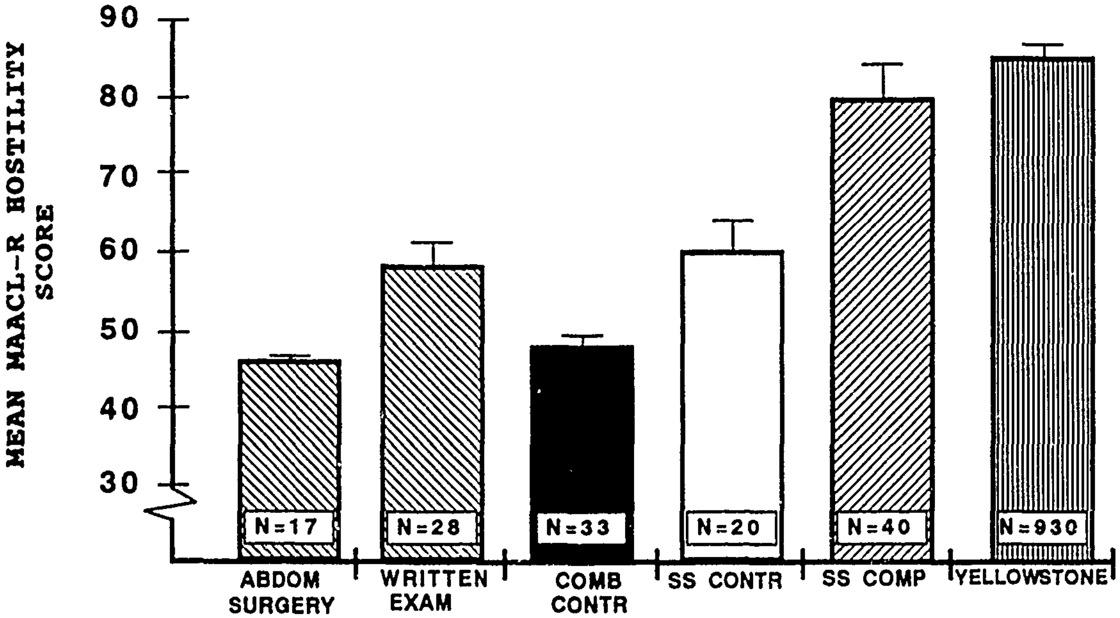


Mean (+standard error) post-stress MAACL-R Hostility scores for each fire-fighting Task Force (TF).

FIGURE 4



Mean (+standard error) post-stress MAACL-R Anxiety scores for the Northwestern University Surgical and Exam protocols, their combined Control group, the Salvo Stress Control and Competition groups, and the Yellowstone firefighters.



Mean (+standard error) post-stress MAACL-R Hostility scores for the Northwestern University Surgical and Exam protocols, their combined Control group, the Salvo Stress Control and Competition groups, and the Yellowstone firefighters.

The comments made by the soldiers bear on the issue of using operations such as the Yellowstone National Park fire-fighting experience as a model of combat. Roughly 40 percent of the subjects were either unwilling or unable to compare their Yellowstone experience to either their experiences in or their ideas of combat. Those willing to make such a comparison noted that the Yellowstone operation shared several common factors with combat. These included the deployment process, family separation, the need for leadership, teamwork, and discipline at the unit level, and the requirement to manage individual differences in stress responses. Other common factors included the sustained nature of the work, with alternating periods of intense activity and boredom, unfamiliar terrain with limited ingress and egress routes and dangerous animals, the physical strain of fire fighting and the long (10- to 14-mile) marches to fire-fighting sites, complications arising from communications, and the unpredictable nature of the fire itself.

Our experiences to date suggest that much valuable information relevant to the behavior and performance of soldiers and their leaders in combat can be collected in situations such as that offered by the Yellowstone National Park fires, because, unlike training, these situations involve real hazards, real dangers, and real consequences in a real world setting. The fire, unlike a human enemy, is neither alive nor is it motivated to defeat the soldiers, but it is, nonetheless, a dangerous and unpredictable foe. Thus, this operation appeared to share several of the stressful aspects of combat, although the generally moderate stress levels observed were lower than we would expect in combat. With the addition of more performance data to the collection effort, such undertakings will be able to provide a steady flow of information on human performance in operational settings.

Future Efforts

Efforts to obtain higher stress groups to extend the range of application of the metric are under way. We are also investigating other stressing procedures for use in soldier-equipment testing, and are exploring other opportunities to apply the metric. The Yellowstone experience has demonstrated that our work has progressed to the point where we can, for the first time, provide the Army with reasonable estimates of stress experienced by soldiers in certain situations. We are currently scheduled to provide a stress assessment for the TOW Accuracy Study described elsewhere in these proceedings. The TOW gunners will fire live missiles under operational conditions at the National Training Center (NTC), Fort Irwin, California, and under more benign conditions on a range at Fort Hood, Texas, where the physical but the psychological aspects of the NTC experience will be simulated. The outcome of this study will indicate whether range performance data, obtained under nonstress conditions, or NTC performance data, presumably obtained under more stressful conditions, are more suitable for use in models.

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TOWARDS A QUANTUM LEAP IN LEARNING OUTCOMES

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By way of introduction, several "war" stories.

I know of only one Army Service School that practices scaling of test scores and even within that school there are many exceptions. Within that same institution, a Colonel served as a school director for over two years. He was reassigned as Deputy Assistant Commandant and served seven months before he learned that his former school scaled test scores. His immediate and horrified comment was: "Why that's almost like cheating.

Only recently did the Army adopt scaling of Skill Qualification Test (SQT) scores. All soldiers within particular pay grades are supposed to take a test each year which purports to assess their proficiency in their occupational specialty. With the cut scores pegged at 60 percent for all tests, the pass rates for various SQT varied wildly. Table 1 shows a typical year when 667 different occupational tests were administered to over 370,000 soldiers. We covered the complete possible range; from zero percent pass to 100 percent pass. This clearly illustrates the horrible consequences of not scaling test scores. In 1986, eight years after the SQT was implemented, the TRADOC Commander, then General Richardson, signed a letter to the DCSOPS, DA recommending scaling of SQT. Scaling of SQT was adopted in the same year.

TABLE 1: SQT PASS RATES

PASS RANGE	# SQT	%
91-100	499	67
81-90	97	15
71-80	44	7
61-70	25	4
51-60	20	3
41-50	10	1
31-40	7	1
21-30	7	1
11-20	3	.4
1-10	2	.3
0	3	.4

In 1987, LTG Forman, then Deputy Commander for Training, Training and Doctrine Command (TRADOC), stated in a memorandum for the TRADOC Commander, "We certainly can't win with Fire Direction centers operating at a 70 percent performance level." His memorandum was a beautifully articulated attack on our practice of designating 70 percent as the standard in our training. He urged grading against a standard rather than relative grading--"based on a curve," which he defined as "...grading students against each other..."

A West Point Department Chairman recently told his instructors (under the assumption that not too many would fail the cut score of 70 percent) that he did not care what they did so long as their test results averaged 85 percent."

Not too long ago a general officer wrote a letter advising a school commandant that one of his courses had an extraordinarily low attrition rate in comparison with sililar courses in Navy and Air Force schools which were from two to three times higher. The general officer then suggested that the school was letting the bad guys through. The attrition rate of the Army course promptly tripled to around 16 percent. Three studies, one by the General's command and two by the Army School, had shown no relationship between school grades and a very hard job criterion. The same criterion was applied in all three of the studies. None of these studies were published.

I have documented cases of attrition rates rising and falling as a function of change in course leadership. In Table 2 is one example, old enough not to get anyone in trouble, taken from annual reports by Continental Army Command, now TRADOC. These were, supposedly, three identical courses that were conducted by three different Army service schools. Prerequisites were the same. The Programs of Instruction were the same--the Signal School was the proponent. Up and down went the attrition rates. Large numbers are behind these attrition rates; in most cases from five to fifteen hundred trainees annually at each school. Think of the human damage and the dollar damage!

TABLE 2: PERCENT ATTRITION RATES IN THE FIELD RADIO MAINTENANCE COURSES CONDUCTED BY THE INFANTRY, ARMORED, AND ARTILLERY SCHOOLS

FY	INF	ARM	ARTY
65	18.1	.9	11.5
64	11.7	6.0	29.0
63	12.2	22.5	36.0
62	5.8	19.0	28.0
61	5.2	17.0	16.5
60	8.7	11.4	--*
59	15.5	0.0**	12.6
58	19.2	14.1	14.8
57	17.8	8.2	20.7
57	24.7	8.9	25.0

Data from USCONARC School Course Attrition Reports. Output each year was volume training; 5 to 24 hundred except where noted.
*No training conducted.
**Output was 53; no losses.

During the tenure of a minority course leader, the minority attrition rate was lower than that of the majority attrition rates. Before and after his tenure, the attrition rates were higher for the minority students.

In a 2500 hundred annual trainee input course, the National Guard students, about one fourth of the total, had an attrition rate nearly five times that of the active Army students. The instructors offered several reasons for the disparity. The first reason offered was that the aptitudes of the Guard students were too low; the Guard was improperly administering the aptitude tests. A commercially vended test of reading ability administered to both active and Guard soldiers revealed no differences in their aptitudes. (Inadequate aptitudes continue to be the most popular reason Army service school instructors offer for high attrition rates.)

The second reason offered by the instructors was that the Guard students weren't trying because they were being trained on a system different from the one they used in their Guard Unit. Comparisons of Guard and Active Army student performance on the tests in question revealed no differences.

Private, one-on-one interviews of nearly a hundred students identified the cause: Instructor bias against the Guard student--the "weekend warrior!" Following the director's private counseling session with the instructors, the disparities in the attrition rates of the active and guard component students ceased.

Most people can relate incidents similar to the proceeding Nearly every collage graduate can recall the course and professor with a high attrition rate reputation. We value rigorous training--our code word for courses which have high academic failure rates. We proudly say "That's a tough course; a lot don't make it through."We rig our training to produce failure. We believe that things are not right unless there are failures. It is our cultural norm that most students be labeled as average and that a few fail and a few others be labeled as superior. We must change our thinking.

Further, we have gotten our training development processes so complicated that we have become lost in them. Stack the set of TRADOC regulations on training development and delivery together with a school's implementing set of regulations and you have a formidable stack. It takes a small Army to exercise staff supervision over these processes. We don't know where we should focus. In the remainder of this paper I will focus on four critical points for leader intervention in the training development and delivery process. These four points for focus represent a complete departure from our cultural norms on how we view the role of testing in our instructional systems. Attend to these four focal points, and only these, and high quality training will result. None of these critical management points are recognized in our present doctrinal literature and none are recognized and practiced by our training leadership.

The focuses of these four management points is, in this paper, limited to cognitive skill acquisition: the acquisition of skills that are procedural, verbal, language, and concept bound. The vast majority of Army service school training is aimed at such learning outcomes.

The first management point, given a particular task or skill to be trained, is to design the terminal test for the instructional unit. We make too many mistakes when we first design the terminal learning objective. And the mistakes are even larger when we design the TLO and the training <u>before</u> we design the test; still, with some exceptions, the prevailing practice. We must determine where we are going before we decide how to get there.

Here are some of the more important considerations in designing the criterion. The ultimate objective of all training is that it transfer to the criterion situation. We know that even seemingly inconsequential decrements in the realism (fidelity) of the training often produce no transfer and even negative transfer. We often hear "identical elements produce transfer of training." So our efforts in training test design must aim towards high fidelity portrayals of job situations. But when we faithfully pursue high fidelity tests we pay a big price: we expend much more effort in both developing and conducting these high fidelity tests.

We also know from research that even very crude fidelities, enlarged photographs for example, possess sufficient psychological fidelity to enable transfer of the training to the criterion situation. Because costs generally increase concurrently with increases in fidelity, the now unrecognized critical question is: How little fidelity will be sufficient to insure transfer? What is the least fidelity, lowest cost training design, that will get the job done. Here we need much better guidance than we now have. Even with better guidance the larger hurdle to overcome is the pervasive distrust of simulation. The typical Army service school instructor is adamant in his/her disbelief in simulation. We resort to simulation only when we can't afford to issue each student his/her own missile on which to practice maintenance.

The multiple choice is widely used and widely accepted. We all were raised on multiple choice test questions. We do not question them. I used to think that I could write multiple choice test items that would produce transfer and that would correlate highly with performance tests of the same skills. From a TRADOC Commander convened study team on the Army's Skill Qualification Test in which I participated in 1985, I now believe that I cannot do so. My job (what a shot in the arm after 20 years out of graduate school) was to search the literature. I found 19 studies over a 30-year period which assessed the relationships between multiple choice tests and high fidelity hands-on tests of the same skills. Most of the studies were done in military training settings and used newly enlisted personnel as subjects.

Table 3 displays the reliabilities reported on both the written and hands-on versions (some of the studies did not report test reliabilities) and the correlations obtained between the written and performance test versions. Understand that every one of these research efforts were confined to narrow portions of the total courses of training--nothing like the heterogeneity/specialization/fragmentation that typically exists in Army technical occupational specialists. Also understand that the research focus in all of these studies was to obtain the highest correlations possible between the two measures. After having plowed through these studies I now believe that no one can write valid multiple choice questions. I also now believe that the Army's SQT program is not valid and can never be valid. Multiple choice cannot measure performance!

TABLE 3. MULTIPLE CHOICE AND PERFORMANCE TESTS: VALIDITIES AND RELIABILITIES

r	RELIABILITY MC	RELIABILITY PERF	VALIDITY
.91-.95	////	/	
.86-.90	/	/	
.81-.85	////	/	
.76-.80	//	///	
.71-.75		/	/
.66-.70	/	//	
.61-.65	/		//
.56-.60			
.51-.55			/
.46-.50		/	////
.41-.45		/	///
.36-.40			
.31-.35			////
.26-.30			//
.21-.25			
.16-.20			/
.11-.15			/

Adapted from Rumsey, Osborn and Ford, 1985

Of special note is that three of the studies addressed electronic equipment troubleshooting. All three studies found correlations of around .4; about 84 percent disagreement between the performance test and the multiple choice version. The authors of the most recent effort (Rumsey and co-authors, 1985), after having gotten the same low correlation, cautiously commented "Perhaps no written test can tap such an ability particularly well."

In addition to the issue of how little fidelity can be sufficient to produce transfer a second and almost unrecognized issue is how small can be the transfer set? An example will illustrate the meaning I intend by the term "transfer set."

We developed training on four application software packages (MS DOS, LOTUS, dBASE, and Multimate) and billed the results as automation literacy. We called this 5-day block of instruction the "Micro Lab." For over a year we did not test outcomes. By 2 o'clock in the afternoon (afternoons were practical exercise time) only a few students would still be in the class room. I forced the development of tests for each of the software packages. We had to know what we were getting out of the 5-day investment. I asked our instructors to select a subset of commands and functions in each package that would be enough, when mastered, to enable the student to proceed on his/her own with the rest of the commands and functions in that package. I used the terms "starter set, entry set, door opener set, and transfer set" to communicate the notion of what would be enough to get the student started.

The intent of the starter set is to form the concepts that drive performance. A friend later suggested the term "navigational skills" to denote the intended outcomes of training on a starter set. The crucial and really only useful outcome is the acquisition of concepts. The form of a command is a concept. How commands are entered is another. The concept of an "A drive," a "B drive," etc., is another. The procedures for executing menu- and prompt- driven functions are concepts. The formation of these concepts is the objective of the training. We know the perishability of cognitive or procedural skills. The game rules are "use or lose." "F6" is the command in Multimate (a word processing software package) which will begin the execution of the "move text" command. Let time pass without use of the move command and we will quickly forget F6. But we will never forget the concept of moving text.

I will use the test results of the word processing package to illustrate what happened with all four software packages and to illustrate the three remaining management points. We selected 20 of the some 200 functions in the wordprocessing software package as the entry set or transfer set. The term "concept" is largely unrecognized and as well, much confused with "skills and knowledges" in the Army's training development rationale.

There is little understanding of how to design training to result in concept formation nor is there much concern for how small an entry set will be sufficient. In Army service schools no one thinks minimum. The opposite thinking is more nearly the norm. A typical pattern repeated over and over across the Army service schools: new instructors initially have difficulty in filling up the allotted time but pretty soon have learned more than they have time to unload and are yelling for more time.

Here is a typical example of this "longer is better" thinking so pervasive in our service schools. A new instructor assumed responsibility for the micro-lab instruction. After several months of experience the instructor decided to revise the training. The work-book needed some fixes. In a casual conversation this instructor commented to me that she was going to add three new functions to the starter set. I promptly asked: "Why add the three?" She responded that the students needed to know those functions. The instructor was startled by my response, almost a yell, of "No. You should be asking what can you safely take out and achieve concept formation/entry level skills?" Here is an area just begging for some hard-nosed research. How do we know that we have identified the minimum sufficient to form the navigational skills/concepts?

It is even sadder that our instructor staffing yard sticks promote longer and more labor intensive training designs. The staffing game rules actually punish efforts to achieve more with less. When you do, the commensurate instructor authorizations are withdrawn. This is not a research issue. Instead, we need to set up a staffing game that rewards minimum thinking.

We also believe that our students could, on their own, master completely different packages on word processing, spread sheets, and data bases. Could they? The probability is quite low that our students will encounter in their future assignments the same software application packages on which they were trained. I believe that they could but to this day we don't know. It would be simple and quick to construct a small test requiring the use of 4 or 5 functions in a different application package. But, we don't do those sorts of things. We lack an empirical orientation. We are not from Missouri when we run training. We much prefer to shoot from the hip. We are constantly fixing training but we rarely check to see that we did. Our training management orientation is process and prescription. It should be empirical.

Returning now to the design of the test of the wordprocessing software. The design of the test became "Do it like you would in the real world." Here is a microcomputer with the application software already loaded on the hard disk. Here is a scratch diskette and another diskette with files on it. The problems illustrated in Figure 1 are typical of those in all four of the tests for each of the software packages.

1. Underline the phrase ...
2. Move the second paragraph...
3. Reset the margins in ...
4. Create a document using the indent key, the tab key, and the format line using the following text..

Figure 1. Examples of test problems

In summary, the first critical management point is training test design. Design towards sufficient fidelity and select the smallest subset that will produce concept formation/ navigational skills.

After having designed the test, we must necessarily make a cut at designing the training. Part of the training design is easy; provide practices that are similar to the criterion items. The catch is that we cannot in advance of experience with our learners, determine the answers to four critical training design questions. (1) How to minimize ambiguity? (2) What is an adequate instructional level of specificity--how far do we unpack the task for instructional purposes? (3) How many, or better, how few practices are enough? (4) Where is part-task and whole task practice required? No amount or kind of task analysis, learning analysis, or prerequisite analysis will answer these four questions. We know too much--we can't put our selves into the shoes of our students. Only students can tell us what is right and wrong. These are empirical questions. We ask these questions only when our orientation is that most of the students we receive can be trained to mastery. This is the intent, little realized, of Terminal Learning Objective thinking. It is the intent of the former TRADOC Commander--now Army Chief of Staff, when he directed implementation of "After Action Reviews" following completion of each instructional unit: What went right, what went wrong, how do we do it better next time? His message was: Find out what is wrong from the students and fix it. This is the second management point. An illustration of this management point follows.

The first test results for the software package are displayed in Table 4 along with selected subsequent class test results in frequency distribution form. Following normal procedures, we would set the cut at 70 percent and begin worrying about high failure rates which, in this case, would be about 31%. We would then lower the difficulty of the questions in order to get more passes. Or, we would become concerned with the quality of our students. It is a frequent game in many Army service schools to pursue a higher prerequisite aptitude. At all levels we are unaware that the predictive validities of our aptitude test scores (from the Armed Services Vocational Aptitude Battery) on Army school course success range from zero to about .60. The median correlation is around .4 to .5. The predictive validities are lower with performance tested courses and higher with norm-referenced tested courses. In either case, raising the prerequisite aptitude score another notch results in inconsequential gains. But we don't know these almost useless relationships and we waste prodigious effort in trying to get aptitude prerequisites raised. Time better spent on finding and fixing the problem.

Had every student passed, the conventional norm-referenced approach would

TABLE 4: RESULTS OF PERFORMANCE TEST OF WORDPROCESSING SOFTWARE PACKAGE

CLASS # 1	CLASS # 2	CLASS # 3	CLS #4	CLS #16
////////////	//////////////	///////////////	////	//////
///////	////////	//////	//////	///////
/////	//	//	////	///
/			/	
/		/	/	//
//				/
	/	/	/	/
		/		///
	/			
/				
/	/			
/			/	
/		/	/	
////////				/
	/	/		
		/		
	/			
	//			
		/		
14	19	20	18	17
39	30	29	19	24

*Number of scorable responses in each test.
**Number of students in each class.

have been to manipulate the test questions to increase their difficulty so as to get some failures. Training and Doctrine Command's new manual on the "Automated Instructional Management System (AIMS)," recently staffed with the Army schools, reflects this conventional norm referenced approach. In the narrative describing the Discrimination Index (the heart and sole of norm-referenced testing), the draft manual states: "This information provides an indication of which test items may be ambiguous, too difficult, or too easy." Illustrative of this thinking: A researcher with a field unit of the Army Research Institute recently delivered a paper in which he demonstrated how the variance of a particular test used in an Army course could be greatly increased by eliminating those questions correctly answered by most students. When most all students learn something, we must stop testing it? Stop training it? How twisted is the logic of norm-referenced achievement testing.

We did not pursue either of the above procedures. Instead, we began an iterative training development approach. We keyed on, and set out to fix, any question/problem that was incorrectly performed by 20 percent or more of the students. You should recognize that this question difficulty goal is the opposite of norm-referenced testing goals. This no-more-than-20% goal is an operational definition of a training design that is good enough for most. It is a design-for-success strategy. It rests on the assumption that given reasonable leadership and decent instruction, most of our students will learn. It is a strategy that says that we can do our job with the talent we get; as defined by the Congress, the political climate, and the economic conditions. Any other thinking is defeatist thinking! Some beautiful things happen when you think and act this design-for-success strategy.

Initially, we found and eliminated huge gobs of ambiguity in the wording of the test problems. The traditional editorial approach doesn't work. It will get some of the ambiguity but much will remain that only the students can identify. Students will find the ambiguities; but only if you expect them to do so and sincerely ask their help. Here again our traditions are strong: hard questions are essential so we simply do not entertain the equally plausible explanation that test question ambiguity may be the reason for poor student performance.

When General Vuono, then Commander of Training and Doctrine Command, implemented the After Action Review (AAR) about 3 years ago—I should say, "tried to implement;" most Army service schools ignored the technique—I directed that they be entered into our training schedules. (I wanted to be sure that I could find them to observe them.) Even with our instructors having completed what I thought was good training on how to conduct an AAR (I took the training too), the first 9 or 10 instructors I observed conducted them incorrectly. All of them failed to facilitate student views. Instead, they invariably defended questions criticized as poorly worded or not adequately trained. To student comments about a bad question or a confusing example, the typical instructor responses were: "Remember I said...," "Remember we discussed...," "You should not have ..." None picked up on the idea that the instructor's role in conducting the AAR was that of a facilitator; that the AAR was a student show.

The initial effort in this iterative training design strategy usually should be focused on the elimination of ambiguity in the wording of the test questions. The remaining gains come from clarifying the wording of the handouts and exercises, providing practice where there wasn't any, and adding more practice. Over several iterations of the instructional unit (as many as nine: you just can't fix every thing in one or two trials), large gains in student performance typically result. One could argue that the Army's present instructional design model intends that the results of the training be fed back into every step of the training design process; flow charts of the model show a feedback loop into every developmental step. But actual practice focuses the training development effort on task analysis, learner analysis, prerequisite analysis and media selection. The implicit assumption is that these efforts will produce correct prescriptions on the previously noted un-prescriptable design issues of ambiguity, level of specificity, part- vice whole task practice, and minimally sufficient practice.

Adequate solutions to these four design issues will not submit to one individual's judgment: training designers, subject matter experts, know too much about the task! They can't put themselves into the shoes of the student. Only students can tell us the adequacy of our training designs. And precision information on adequacy is obtainable only from their performance on our training tests. You can get feelings and emotions from student written critiques but you can get the precision information you need only from your tests results. All of the judgments, all of the reviews, all of the development steps, all of the analysis, pale into insignificance in the powerful light of the simple and unambiguous fact that 80% of our students incorrectly performed a particular function. We know exactly what we must fix; but not necessarily how to fix. Several iterations may be necessary to achieve the fix. This powerful link between the terminal learning objective and the training test is not recognized in our doctrinal literature and is untapped in practice. The belief that questions must not be too easy predominates. The emphasis in training development and management is on form, process, expert review. Large staffs invest much effort in managing the individual steps in the process. There is no staff emphasis on test outcomes. An up-to-date lesson plan at the visitor's desk in the back of the classroom together with a copy of the Program of Instruction and a seating chart are the signs of good training. Pages and pages of doctrinal guidance on the processes of training development but none on how to interpret a test outcome where 60% of the students missed a test question. Our training management is now process oriented. Our quality yardsticks are all of the forms completed and classroom observations with exhaustive checklists of instructor behaviors. Rather, we should focus on the terminal learning objective--could the students perform; and on the After Action Review--what went right, what went wrong, and how can we do it better next time. An iterative training design and management approach; an empirical approach.

Tables 4 illustrate the typical results from applying this iterative training design strategy. These are selected results over 16 classes. The improvements in student performance resulted from the trial-test-revise approach. Try a fix, then see if it works. No eyeballing! Only results count! Continue the trial-test-revise approach until no test items are missed by, on the average, 20% of the students. Why 20%? Why not 10% or 5%? I admit to an experienced based judgment call here from over 20 years of applying this training design and management approach. Twenty percent is achievable in all cases that I have dealt with. A higher quality standard is not worth the effort. That 20 percent gate seems to be a threshold. At this level, most all of the students achieve very high performance. Many max the test and most others miss only a few.

I should note that cut scores are raised as training quality improves. Initially they are set very low--we would rather err in favor of the student when we have little training quality. I should also note that after we have "debugged" a new test and gotten some degree of training quality, we develop two more versions of the test. Here we seek to test, in the sum of the three test versions, all of the learning outcomes we specified in the beginning in the Terminal Learning Objective.

Now for the third management point; managing student learning. This 80% training quality outcome opens an entirely new, and I commend to you a far better, approach to managing student learning. Notice how conspicuous are the few low test scores. They stand out with compelling clarity. They are almost alone. A generalization in measurement is: the more extreme the score, the more meaning it has. We have considerable confidence that the lowest scoring student did not profit from his or our efforts. He or she should do better. We have a powerful basis for counseling that student.

Now one transgression does not a failure make. But, get your act together Student! Continue on with that kind of performance and we will begin to believe that you really haven't gotten it together. Or just bust one more and don't shine on the other tests--that is, hug the margin, just barely pass, establish a trend of marginal performance, and you have earned at the least an adverse report card and more likely an academic elimination. And by the way Student, don't excuse that miserable performance with: We didn't teach you. We confused you. You freeze up on tests. The instructor didn't help you. The instructor did his/her job (and gets recognized for it). What is your problem?

We really have had failures under this trainee management approach. But not many. Immediate, without exception, and in writing counseling of each test failure, usually gets magnificent results. And we have never had a student argue with the label of an unacceptable test performance. They do know that we have set a cut score higher than 70%. They do know that we scale test scores. While many will weakly protest that 70% aught to be passing, none have even hinted at challenging the concept of an extreme score, even though it is above 70%, being labeled as a failing score. The frequency distributions are equally convincing to students.

I believe that some students go into an Army training course with the intent, likely unconscious, of riding or costing on the curve; that is, the lower part of the curve. It is a real shock to them to discover that there is no lower part of the curve.

Most instructors and training directors at all levels quickly adapt to frequency distribution displays of test scores as basis for evaluating student performance and, in extreme cases, declaring academic failure. Using the same frequency distribution as basis for judgments of training quality is equally accepted by staff and faculty. Note that these critical judgments are based solely on the pictures and patterns of performance as revealed by the frequency distribution displays of actual raw scores. We also use the frequency distribution displays with students when we counsel test failure. We make no use of the accumulative average.

We must rationalize our decisions about students and about our training quality. This kind of thinking is also initially scary stuff. There are no magic numbers that make our decisions for us. We must interpret. We must detect, and we now have the means to do so, that a particular set of test scores is out of line with the norm; that the many failures on one test mitigates one student's failure--we had a hand in the failure; that yes Student, you maxed a test but so did most all of the students and that does not compensate for your otherwise overall consistently miserable performance.

The fourth management point is concerned with efficiency; that is, have we allocated the minimally sufficient training time. The concern here is to optimize the learning time. It was a frequent observation during the programmed instruction movement that average learning time decreased as the programmed instructional materials were refined and improved from the results of the large group trials. The original 5-day microlab stretched to 8 days in response to strong yells from the instructors that they did not have enough time to train all of the skills we had demanded on the performance tests for each of the application software packages. But as time passed and students began maxing or nearly maxing all four of the tests, again we began to notice that the microlab would be nearly empty rather early in the afternoon. We arbitrarily cut the allotted time to 4 days and did not change the standards on each of the software package. Student performance dropped slightly but not enough to Warrent a change. And some students even started showing up at night in the microlab. This instructional unit is now rigorous: Not in the traditional sense of high failure rates and hard questions, but in the sense that the slower learners are pushed and have to spend time outside class hours to keep up.

Should you try this approach to managing training quality and student learning, recognize that you are cleanly breaking away from a set of student achievement testing practices that are deeply imbedded in our culture. Successful adoption of this approach requires much TLC and close oversight in the beginning. And this beginning is not an afternoon.

Figure 2 lists 10 issues that you will encounter over and over as you implement the training design and management approach I have described in this paper. Any one of these is good for an argument with most Army service school people. You need a year or more of close oversight to insure a successful graft. Much one-on-one instruction and strong leadership is needed. The advocate must be in the chain of command or be visibly near the flagpole. And

	ISSUE	OUR TRADITIONS	MUST ADOPT
1.	BELL CURVE	-GOOD TRAINING -MUST HAVE TO RANK	-POOR TRAINING
2.	MULTIPLE CHOICE	-BEST	-RARELY APPLIES
3.	DISCRIMINATORY QUESTIONS	-GOOD; IDENTIFIES GOOD AND BAD STUDENTS	-BAD; ISOLATES SPECIFIC AREAS OF POOR TRAINING
4.	STANDARDS	-RELATIVE	-ABSOLUTE
5.	OPEN BOOK	-NO	-YES (IF TASK DELAY TOLERANCE)
6.	AVERAGING TEST GRADES	-YES, TO RANK AND DETERMINE PASSING	-NO. SUPERIOR PERFORMANCE ON ONE TASK CANNOT COMPENSATE FOR INFERIOR PERFORMANCE ON ANOTHER TASK
7.	INDIVIDUAL COMPETITION	-YES. PROMOTES LEARNING	-NO. SUPPRESSES LEARNING
8.	TEST REQUIREMENTS	-HIDDEN	-OPEN. (USE PRACTICE TESTS)
9.	2ND, 3RD CHANCES	-NO. ("YOU GET THE GRADE YOU EARNED")	-YES. OBJECTIVE IS TASK MASTERY
10.	WEIGHTING TEST ITEMS	-YES, ACCORDING TO RELATIVE VALUE	-NO. MEANINGLESS

Figure 2. Beliefs we must change

predict its demise with new leadership that is not privy to, nor sympathetic with, the rationale. I have seen this occur over and over.

By way of summary, the critical management points in what I might should call an "objective controlled" instructional design and management system are; first design high fidelity performance tests. Identify the entry set and while you are at it try to think lean; that is, what is the smallest set that will be minimally sufficient. Recognize that this thinking is necessarily judgmental: we have little research to help us. Now, this issue is not even recognized in our doctrinal literature. Even a judgemental application of this thinking would likely result in significant reductions in training costs.

Second; apply an iterative training design strategy. Just believe that no matter what you do you will not get your training right the first time you run it. Trial-test-revise until you achieve the 80 % solution: at least 80 percent of your students correctly perform in all areas. Your training is then good enough for most students.

Third; manage the learning of your students by developing and maintaining frequency distribution displays of raw test scores. Concurrently, monitor the quality of your training via the frequency distributions.

Fourth; optimize the training time by cutting back on allotted time until student performance begins degrading and some start showing up at night.

Our academic leadership has indoctrinated our culture with the norm, with the belief, that training and education tests must be rigged so that the outcomes are; some failures (the higher the numbers, up to a point, the more rigorous the training), most average, and a few superiors. How many times have I heard students say "Oh I am just average." We have indoctrinated huge portions of our population with the belief that they are just mediocre, that they are not good learners. Our academic leadership has fostered in our culture the horrible belief that there must be failures, and that only a few can learn a whole lot. Bell curve grading is our norm. Our standard has become mediocrity. A general officer stops pass-fail grading in a course because it "promotes mediocrity." A sergeant opposes open book testing because "They will get'em all right. Every body will pass." Those are verbatim quotes. A Warrent officer directing a large volume training program is adamant that test questions have difficulties of point eight or higher. Things really are not right when lots of students max an exam. Very few of these advocates can articulate the rationale for norm referenced evaluation. "Inter-item homogeneity measures, discriminatory item power, Kuder-Richardson formula 21, test reliability, etc.," are alien and somehow threatening terms to most of our education and training leadership at any level. Even though lacking understanding of the norm-referenced rationale, particularly its mathematical basis, we still expect and demand its outcomes. Even the vast majority of parents of school age children expect such outcomes (but rarely for their own children). College presidents routinely issue letters of censure to instructors who grade too high. School superintendents are proud that their school system "grades hard." Training directors believe that competition promotes learning and are unaware that the considerable research on competitive learning environments shows that non-competitive learning environments are associated with better learning outcomes (Kohn, 1966). They believe that school should be competitive and even demand that it be competitive. And bell curve grading is competitive. It pits each student against every other in a zero-sum game. A game that brings out the beast in us. Yet the essence of combat is squad against squad, division against division. Teamwork is an essential of combat. But the bell curve has become our cultural norm. And we have long since forgotten why.

We must kill bell-curve grading. We must design for success. We must believe that we can design for success. When we believe that we can, we will.

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SINCGARS Operator Training Evaluation: Implications for Cost Savings in Army Training[1]

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This paper describes a training evaluation conducted by the U.S. Army Research Institute for the Behavioral and Social Sciences (ARI) as part of the U.S. Army's Manpower and Personnel Integration (MANPRINT) program. MANPRINT evaluations are conducted in connection with Army materiel acquisition and may involve any of the six MANPRINT areas of research: manpower, personnel, training, human factors engineering, safety, and health hazards. The particular research described here concerns the acquisition of a combat net radio known as SINCGARS (pronounced "Sing-gars"), which stands for Single-Channel Ground and Airborne Radio System. SINCGARS will replace the Army's current backpack and vehicular radios. Because it is a "general user" item, all soldiers will be trained in its use.

Background

SINCGARS is a VHF-FM receiver-transmitter developed and manufactured by ITT Corporation. (A second source ground radio production contract was awarded to General Dynamics in July 1988.) Its primary role is to provide secure voice transmission for the command and control of maneuver forces. It will be the primary means for short range communications at echelons below division level and for combat support and combat service support units throughout corps level. One model is presently in limited use in Korea and in the U.S. at Fort Sill and Fort Gordon.

A significant feature of SINCGARS, not shared by it predecessors, is its jam-resistance, or electronic-counter-counter-measure mode, which is accomplished by "frequency-hopping." In this mode, the radio changes transmission frequency many times a second. All radios in a net are capable of hopping simultaneously from one frequency to another within a prescribed set of many frequencies called a hopset. The radio is also capable of single-channel (non-frequency-hopping) communications, data transmission, and channel scanning. It has push-button tuning, an LED display, selectable power outputs, a whisper mode, an expanded frequency range, built-in self-test capability, and nuclear hardening against electromagnetic and radiation effects. The most recent models of the radio also incorporate integrated signal coding circuitry, which affords communications security heretofore provided by additional external equipment. The price is in the neighborhood of $12,000 per unit. The Army plans to purchase over 350,000 units. The total cost of the system has been estimated to be around $6 billion.

The development of SINCGARS actually began in 1974 with Army approval of the Required Operational Capability document. ARI began evaluating SINCGARS

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[1]This report is adapted from "SINCGARS Operator Training Evaluation," a larger report currently in preparation.

in 1982 in connection with the Army's initiation of operational testing on the system, and has participated in each major test since that time. Much of the data for this report was collected during an operational test at Fort Sill, Oklahoma performed by the U.S. Army Test and Experimentation Command during March, April, and May 1988. Additional data were obtained in the following months and during operator training conducted prior to a subsequent operational test of the system at Fort Hood, Texas in October 1988.

Operational tests of SINCGARS have typically followed a general design in which there is an initial training phase for operators and maintenance personnel. Training may be followed by a period of a week or two referred to as "unit familiarization," a largely uncontrolled situation during which the radios, which have been distributed to the participating Army units and mounted in some of their jeeps, tanks, and other vehicles, are used by the units as they desire. Next comes a pilot test, perhaps another week, in which an attempt is made to conduct operations exactly as they will be conducted during the subsequent test-for-record, which will last for two or three weeks. During the record test, the participating units engage in a controlled field test that attempts to simulate a typical field exercise. There is a conspicuous absence of battlefield realism, however, which would make the test more expensive and introduce many additional uncontrolled variables. Regardless, operations are carried out in the boondocks, sometimes 24 hours a day, under natural conditions of weather, supply, movement, and so on.

Evaluation Objectives

Prior to 1988 most of ARI's efforts in SINCGARS evaluation were concerned with human factors aspects of the radio, including operational procedures and their complexity, human engineering design, and the adequacy of operator's manuals as training and field documents. The results of that work led to significant improvements in the system, especially in the area of machine interface. However, the radio remains significantly more operationally complex than the radios it is replacing. Consequently, the Army is facing a huge initial and remedial training burden--at a life cycle cost that threatens to equal the cost of the hardware system alone. The amount of time typically devoted to training a SINCGARS operator has been 10 to 15 times as great as that required for its predecessors. Such a requirement invites research directed to maximizing the effectiveness of SINCGARS training and minimizing its cost.

The training evaluation described here pursued the following six primary objectives:

1. To determine the efficiency of the SINCGARS operator training course in its expenditure of time for students and instructors.

2. To evaluate the effects of shortening allotted training time for SINCGARS operators from four to three days.

3. To relate operator critical task performance times to:

- o SINCGARS operator testing criteria established by the U.S. Army Training and Doctrine Command (TRADOC)
- o Operator scores on the Armed Services Vocational Aptitude Battery
- o Operator performance on the SINCGARS Learning-Retention Test--a simulated hands-on performance instrument
- o Class size
- o Student-to-instructor ratio
- o Student-to-radio ratio

4. To estimate operator performance decrement during intervals of no practice (6, 11, and 16 weeks), and to validate previous studies of operator skills and knowledge decay.

5. To obtain operator evaluation, commentary, and suggestions regarding the quality of their training and training materials.

6. To identify common post-training performance errors of operators and weaknesses in their skills and knowledge base.

The last objective is not covered in this report; objectives 3, 4, and 5 are covered in part (see Footnote 1).

Method and Results

Description of Operator Training Course

The object of evaluation was one of 16 SINCGARS operator training classes taught in preparation for an operational test conducted at Fort Sill in the spring of 1988. The course consisted of four days (34 hours) of instruction followed by a day reserved for testing. Training and testing were performed by 12 civilian instructors (3 per classroom). Classes were taught in day and night shifts over a one month period in March. The course, based upon input from ITT Corporation, was developed by TRADOC.

Each classroom contained 13 radios and was prepared to accommodate 26 students at a time, 2 students per radio. The total number of students taught during the month was 367--an average of about 23 students per classroom. The actual number of students in a class varied from 11 to 42. The total number of scheduled instructional hours, excluding lunch and breaks, was 22 (nominally, 5.5 hours per day).

The observed class was by far the largest of the 16 classes, containing 42 students. The average number of students for the other classes was 22; range, 11 to 26. Detailed observations were made by a research psychologist throughout the course. Events and situations related to the variables under examination were documented as they occurred.

Course Efficiency Analysis

The purpose of this analysis was to obtain an accurate estimate of how efficiently the basic SINCGARS operator course made use of student time. A very conservative definition of "efficiency" was employed: For a given student, the only time counted as "inefficient" was that during which the student was, in relation to the purpose of the course, virtually idle--that is, not engaged in learning-related activity. A certain amount of unused time is, of course, inherent in any course of instruction; therefore, the analysis is not meant to imply that every wasted minute can be eliminated, but to provide a baseline against which the effects of future course improvements can be measured.

Procedure. One of the 16 courses (4th week, day shift, Class 1) was observed in its entirety and comprises the basis for this analysis. At regular intervals, often as short as one minute, the course evaluator recorded the number of students who appeared not to be engaged in any course-related learning activity whatsoever, either active or passive. If it was not obvious that a student was idle, the observation was not counted.

Similar observations were made of the assisting instructors. At any given time, one of the three instructors was in charge of the class, while the other two assisted as requested or as they saw fit. The time spent by the instructor in charge during any particular time interval was always counted as instructional time without regard to its effectiveness. However, a close accounting was made of the extent to which the two assisting instructors participated in the ongoing instructional activities. As in the analysis of student participation, the only time counted as inefficient was that during which there was no discernible instruction-related effort.

Efficiency results for students. Table 1 depicts, by day, the amount of time consumed by the students versus the amount of time available. Time available is instructional time--the actual amount of time spent in the classroom. Consumed time is that during which at least minimal learning-related activity was observed. The difference between available and consumed time is the amount of unused, totally nonproductive, student time. Hence, overall-hours-consumed represents a very conservative estimate of the amount of time that SINCGARS operator training might be expected to require if it were conducted with maximal efficiency.

Table 1

Use of Instructional Time by Students

Day	Actual hours available (Nominal = 5.5)	Hours used	% actual time available	% nominal time available
1	5.6	4.8	85.7	87.3
2	5.5	4.5	81.8	81.8
3	5.6	3.8	67.9	69.1
4	5.2	2.5	48.1	45.5
Overall:	21.9	15.9	72.6	72.3

Table 2 portrays the percentages of idle, or unused, student hours during all half-day course segments. Two strong trends are apparent: The number of idle hours increased (a) from morning to afternoon on each of the four days and (b) from Day 1 through Day 4 for both morning and afternoon sessions. Indicative of the strong increases in idleness as the course progressed is the fact that the percentages for Mornings 2, 3, and 4 were each higher than the overall percentage for the previous day.

Additional, non-quantified observations were (a) that idleness appeared to increase in proportion to the distance between the students and the front of the classroom (instructor) and (b) that the bulk of unused time could be directly attributed to a lack of structured activities for the students.

Table 2

Distribution of Idle Student Hours

Day	Morning (%)	Afternoon (%)	Overall (%)
1	6.7	21.5	13.7[a]
2	14.8	22.6	18.4[a]
3	19.0	43.7	31.6[a]
4	47.6	58.8	51.3[a]
Overall[b]:	22.2	34.1	27.5

[a]Calculated from morning and afternoon values, each weighted by amount of time observed.
[b]Calculated across days, each day weighted by amount of time observed.

<u>Efficiency results for assisting instructors</u>. Table 3 shows the results for assisting instructors only; the amount of time unused by the instructor in charge was minimal. Again, hours used is the amount of time involving at

least minimal instructional activity, irrespective of its extent or effectiveness. As for the student data, these data are very conservative. Furthermore, it is reasonable to hypothesize that assisting-instructor utilization would be even less efficient in smaller classes, where it is expected there would be less demand for their services. This hypothesis would, however, have to be tested.

Table 3

Use of Instructional Time by Assisting Instructors

Day	Actual hours available (Nominal = 11[a])	Hours used	% actual time available	% nominal time available
1	11.2	4.3	38.4	39.1
2	11.0	2.7	24.5	24.5
3	11.2	6.8	60.7	61.8
4	10.4	(Unrecorded)	na	na
Overall[b]:	43.8	13.6	40.7	41.2

[a]5.5 hours per instructor. [b]First three days only.

Table 4 shows the percentages of unused instructor time for the assisting instructors for each half-day session during the first three days of the course. Observations for the fourth day were not recorded because of conflicting requirements; however, the amount of unused time on the fourth day appeared to be as great or greater than on the previous day. It can be reasonably concluded that approximately 60 percent of the assisting instructors' time was <u>not</u> utilized. Like the pattern for students, the pattern for assisting instructors showed an increase from Day 1 to Day 2. The 3rd day, however, consisted of a great amount of loosely structured and unstructured student practice, during which the instructors often mingled with the students to answer questions, solve equipment problems, etc. Day 4 was similar to Day 3, although perhaps less structured.

Table 4

Percentages of Unused Hours by Assisting Instructors

Day	Morning (%)	Afternoon (%)	Overall (%)
1	58.5	63.9	61.1[a]
2	75.3	76.6	75.9[a]
3	39.8	36.1	38.0[a]
4	(- - - Unrecorded	- - -)	na
Overall[b]:	58.3	59.4	58.8

[a]Calculated from morning and afternoon values, each weighted by amount of time observed. [b]Calculated across first three days only, each day weighted by amount of time observed.

Performance Criteria

Procedure. At the end of their four-day block of basic operator training, all students trained during the month were required to pass a hands-on criterion performance test, which was part of the official TRADOC training materials. The test required each student to perform 18 critical tasks, each within a predetermined time limit. If the student accomplished a given task in the allotted time, a "go" was awarded. To pass the exam, the student had to receive a "go" for all tasks. If any "no go's" were obtained, which was rare, the student received immediate remedial training and was then retested. Ninety-nine percent of the students passed the exam. At the request of ARI, the performance times were recorded for each task and each student. (The recording of performance times was not an official part of the final exam procedure. Normally they would go unrecorded.)

Results. There was a large discrepancy between the criterion times established by TRADOC and the actual performance times. The mean time allotted for the students to complete a given task was, on the average, more than three times the mean amount actually required to complete the task. Hence the test was capable of screening out only the most drastic of performance shortcomings, and it was incapable of making any qualitative distinctions whatsoever among students. It is evident, then, that the TRADOC criteria, serve no didactic purpose and that they should not be used in future testing without revision. On the other hand, the mean performance times observed in this evaluation could very well serve as rough criteria for future instructional use.

Class Size, Student-to-Radio Ratio, and Student-to-Instructor Ratio

Procedure. Because of equipment limitations and the larger number of students in the observation class, the student-to-radio ratio was relatively large: 3.2 students per radio versus 1.7, on the average, in the smaller classes. All the classes, however, had three instructors. To compare the performance of the students in the large and small classes, data from the

Results. Figure 1 plots for each retest the adjusted mean individual SLRT score (percent correct). As expected, performance generally decreased as the interval between the baseline administration and retest increased. By the fourth retest, the decay is seen to level off. (Of course, it would be expected to continue at a slower and slower rate as time passed.) This decrease in performance level, which occurred during the first 10 weeks of the 3 1/2-month period after the completion of training experiences, represents an average performance loss of approximately 20%.

The Pearson product-moment correlation coefficient for the relation between test-retest interval and group mean percent correct was -.85 ($t[8] = 4.53$; $p = .01$, one-tailed), indicating a strong tendency (coefficient of determination = .72) for performance to decline during the first couple of months.

It had been expected that the highest SLRT performance levels would be observed during Retest 1, just after the field training. At that point the operators had had not only a week of classroom training but also another week of unit familiarization training and three weeks of intensive field training. The adjusted mean percent correct for Retest 1 was 79.1. For Retests 2, 3, and 4, the corresponding combined adjusted mean was 63.6. The difference, tested with analysis of covariance, was statistically significant: $F(1, 76) = 36.09$, $p < .001$.

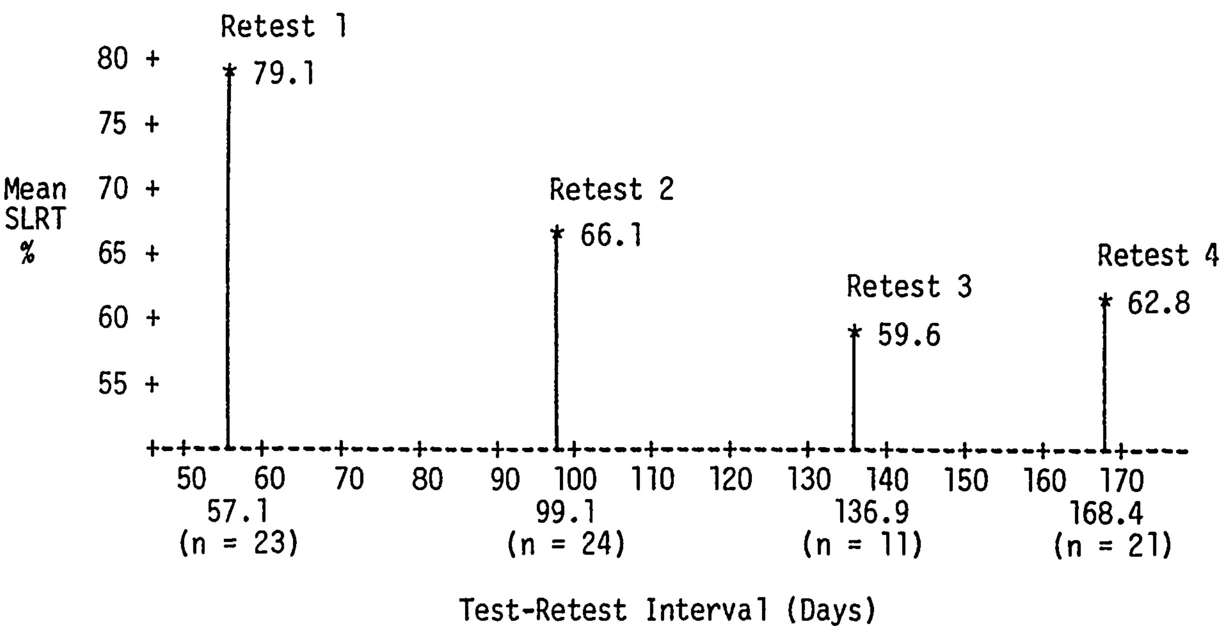

Figure 1. SLRT performance across time.

Effect of Decreasing Allotted Instructional Time from Four to Three Days

Procedure. As noted earlier, the operator training course consisted of 34 hours of training plus 8 hours set aside for end-of-course testing. For a subsequent operational test, which took place in the fall of 1988, the operator training consisted of 24 hours (three days) plus testing on the smaller classes were combined and compared to those of the larger class. Two variables were examined: the final exam performance times and scores on the SINCGARS Learning-Retention Test (SLRT).

The SLRT is a paper-and-pencil, skills and knowledge test. All of the skills items and many of the knowledge items simulate the visual aspects of the real task; for example, the student may be required to answer an item by circling the correct switch position on an illustration of the control panel of the radio.

Analysis of variance was used to compare the two resultant groups on both the criterion test times and the SLRT scores.

Results. Table 5 shows the mean times for the criterion performance test and the mean percents correct for the SLRT. On the criterion test, the large class seemed to perform slightly better, although the result could have been due to chance. On the SLRT, the large class again performed better. The difference was statistically significant, although not large in a practical sense. Thus, the larger class suffered no performance loss, as one might have expected. (The overall mean SLRT percentage for all classes, including the large class, was 71.7. This percentage is similar to percentages obtained in the past, which indicates that the current students were roughly comparable to previous classes in post-training skill and knowledge levels.)

These results suggest that, within the range of values observed, class size, student-to-radio ratio, and student-to-instructor ratio may not be of uppermost importance for SINCGARS training, other things being equal.

Table 5

Comparison of Large Class With Smaller Classes

	Large class (mean)	All smaller classes (mean)	Statistical significance[a]
Criterion test	11.3 minutes	12.0 minutes	$p = .25$
SLRT	75.7% correct	71.1% correct	$p = .02$

[a]Approximate probability that the difference between the large class and all of the smaller classes combined was a chance occurrence.

Performance Decay over Time

Procedure. Operator performance level was remeasured with the SLRT at the end of the field test phase of the operational test and approximately 30, 60, and 90 days later. No practice occurred between the retests. The retest data (percents correct) were adjusted via analysis of covariance procedure to remove the effects of intergroup differences in baseline performance on the first SLRT administration. This adjustment allows a more meaningful comparison of the retest groups.

fourth day. The content of the latter course contained all of the content of the previous one. Since the findings for the earlier test had shown more than a day of unused time, it was reasonable to hypothesize that the 24-hour training course might be equally as effective as the 34-hour course. The test of this hypothesis consisted of comparing across the two courses the mean post-training performance time for completing the 18 critical tasks during the final examinations. The sample size for the earlier group varied slightly across critical tasks because of missing data on some of the tasks; it ranged from 361 to 364. The sample size for the subsequent test was considerably smaller; it was 17 for each task.

Results. Despite the differences in sample size, the differences for individual critical tasks were mostly quite small, and the difference between the two overall means (one second) was negligible. To test the latter difference for statistical significance was considered fatuous; therefore, no test was conducted. The data as a whole strongly supported the hypothesis that a three-day course would be as effective as a four-day course.

Summary of Findings

1. For students, approximately 28% of classroom time was completely wasted.

2. For assisting instructors, approximately 59% of classroom time was completely wasted.

3. The TRADOC student performance criteria applied in the final performance examination were so lenient as to permit virtually all students to obtain certification as SINCGARS operators regardless of the level or quality of performance. The criteria served no purpose.

4. Class size, number of instructors, and student-to-radio ratios, customarily assumed to be important instructional variables, were unrelated to student performance measures in SINCGARS training within the range of values observed.

5. Without continued practice, new (but skilled) SINCGARS operators can loose 20% of their peak performance level within the first 10 weeks.

6. An experimental three-day SINCGARS operator course produced student performance levels equal to that of the standard four-day course, while presenting the same content.

Discussion

The Cost of SINCGARS Operator Training

An unofficial estimate of the cost of signal school training per soldier per week, obtained from the TRADOC System Manager for SINCGARS, was put at about $1,000. (The preciseness of the estimate is not highly important to the following argument.) With this figure and certain assumptions pertaining to force strength, training hours (both initial and remedial), and personnel turbulence, it is possible to derive an estimate of the 20-year life-cycle cost of SINCGARS operator training. Given the current training scenario, as described in this report, the outside figure for that cost could approach $6 billion--as much as estimates for system acquisition costs. This is 10 to 15 times the corresponding cost for training operators on SINCGARS predecessors. Thus, in terms of both dollars and time, the training burden associated with SINCGARS is very heavy.

Each of the findings presented above is related to the cost of SINCGARS training, some more directly than others, but each pointing to areas in which the cost of training could be reduced either by effecting decreases in required training time or increases in training effectiveness.

Student Classroom Time and Course Length

The inefficient use of time by the students in this study was not the product of a lack of motivation, but, rather, a lack of course content. There were no programmed, constructive activities available to fill the time gaps. Furthermore, it is not apparent that there should have been. (Recall that the time segments under discussion were those in which course related activity was totally absent. The remaining time, during which at least minimally constructive activity was taking place was not specifically evaluated for its efficiency, but it was apparent that much of it could have been used to better advantage.) It would appear, then, that the course could be arbitrarily cut by 25% without detriment to operator performance, relative to current performance levels. That would translate to life cycle savings of one day per soldier for perhaps 4 million soldiers (close to 20,000 work years) and as much as $1 billion over the life cycle, or $50 million per year.

Performance Decay Over Time and Human Factors Engineering

It seems apparent that soldiers will require either periodic remedial or refresher training if their operational skills are to be maintained--a requirement directly related to the operational complexity of the machine. Although human engineering factors were not of primary concern in this study, it is worth emphasizing here that the potentially huge training burden placed on the Army by SINCGARS is, by and large, a direct consequence of the lack of sufficient attention paid to human factors variables during the design and initial developmental stages of the system. The origin of most of the common performance errors observed (but not reported here) can be traced directly to the operational complexity of the radio. As a general user item, SINCGARS should be operationally uncomplicated. In the acquisition of new systems, training should not have to be called upon to bear the consequences of inattention during the design stages to matters of operator interface and operational complexity. Training time is money that must be spent over and over again throughout the life cycle of the system.

Performance Standards and Quality of Training

A factor that further confounds SINCGARS operator performance decay data is the lack of objective and independent measures of the quality of operator performance. The normal, or average, performance level on the SLRT is about 75 percentage points, and a loss of, say, 13 points (typical for a two months period without practice) would reduce the performance level to about 65%. But because there is, as yet, no objective measure of how adequate 75% is, there is also no objective way of stating how adequate or inadequate 65% is.

About the only insight into this problem comes from subjective observations by ARI and other test personnel that students fresh out of SINCGARS operator training often have difficulty establishing frequency-hopping nets in the motor pool prior to going to the field with the radios for the first time. Consequently, additional instruction is typically required after classroom training in order to achieve minimally adequate crew and system performance. Subjectively, then, 75% indicates a level of post-training performance that is lower than desirable. Furthermore, the level of post-training performance, as here measured, was unrelated to course length (three vs. four days). Thus, it seems that training needs not to be longer, but shorter and better.

Additionally, if arbitrary shortening of the four-day course by one day produces no decrement in operator performance, one must ask what would be the effect of shortening the course even more. The data, which showed that the 34-hour course contained 9 unused hours, imply that further substantial shortening without concomitant improvements in quality and efficiency may not be successful.

The performance criteria provided by TRADOC should be discarded, and viable criteria for adequate performance of critical operational tasks should be developed. The primary purpose of such criteria would not be to fail students who do not meet them, but to constitute goals toward which students can strive and measures against which instructors can gauge student progress. The two independent sets of performance times obtained in this research fairly well validated each other. Consequently, until further research is done, weighted averages from the two sets of figures should constitute useful indications of how fast the typical soldier can be expected to perform critical operational tasks.

Number of Instructors and Radios

Ostensibly, the primary reason for striving for high instructor-to-student ratios is to provide a greater measure of individual attention to students. But high ratios can be achieved either by decreasing the number of students in single-instructor classrooms or by increasing the number of instructors per classroom. The latter is less demanding of physical training space, but as this study indicates, can lead to an inordinate amount of wasted instructor time--time that could be better spent teaching another class. There is little reason for having three instructors in a classroom, if almost two-thirds of the assisting instructors' time is unused. As for the students, the problem is not one of unmotivated instructors, but of course structure. It would be difficult indeed for both assisting instructors to maximize their individual use of classroom time without greatly interfering with the lead instructor as well as each other and the students. Consideration should be given to increasing rather than decreasing the number of students per instructor. The ideal ratio is an empirical question, the answer to which should be determined by objective evaluation.

A parallel argument applies to the question of ideal student-to-radio ratio. Diminishing returns are encountered at some point as this ratio is decreased, assuming limited funds for equipment. Essentially, the feasible choices for the present classroom situation are one, two, three, or four students per radio. One student per radio (the ratio preferred by students) seems impractical; four begins to exceed spatial requirements and is unpleasant for students. The current data indicate that three students per radio may be equally as effective as two. Therefore, without additional research, the ideal choice would seem to be three.

Conclusion

The SINCGARS school-training package contains no self-correction or self-improvement loop. There is no systematic, effective mechanism whereby lessons learned are incorporated into future training development. Thus, mistakes and inadequacies are repeated over and over again, and needed changes are not incorporated. Therefore, a training enhancement project should be initiated with the goal of achieving a 16-hour curriculum through appropriate research and development. If a 24-hour course can be realized, as it was in this study, with no course changes except a reduction in hours, it stands to reason that further reductions could be achieved with a little effort--that is, through improvements in instructional methods and materials. The minimization of SINCGARS training expenditures, both of time and funds, would probably be difficult to achieve otherwise.

The proposed research should exercise experimental control over training variables so that various training formats and methods could be adequately compared and appropriate instructional materials and methods developed. The anticipated cost of the project would be insignificant in comparison with the potential savings a 16-hour course would yield. Such savings, over the life cycle, could be as high as $2 billion, using the four-day course as a baseline. This amounts to $100 million per year, or a total of 40,000 work years.

A final point: SINCGARS is one system among many.

#111

TITLE: Defense Mapping Agency Land Warfare Support

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ABSTRACT:

The current organization and structure of the Defense Mapping Agency (DMA) is described with a focus upon Digital Terrain Data Products available to DoD land warfare system developers. Included are summary descriptions of new DMA prototype digital data products.

No Paper Provided

The terrain analysis system "Carat"

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ABSTRACT

"Carat" is the name of a research project at the U.S. Army Engineer Topographic Laboratories. The objective of Carat is the same as the mission of USAETL: to improve the Army's capability to visualize, understand, and exploit terrain and other physical aspects of the battlefield. Carat is also the name of a computer system that is part of the project; it is the medium for reporting progress of the research, demonstrating functionality, and getting feedback from users. This paper describes the problem definition phase of the Carat project and reports preliminary results.

1. BACKGROUND

The U. S. Army Engineer Topographic Laboratories (USAETL) has a close association with the military occupational specialty 81Q, Terrain Analyst. One laboratory within USAETL is called the Terrain Analysis Center; it makes special products by request. Another laboratory is responsible for the Digital Topographic Support System (DTSS), to be fielded in the mid 90s. DTSS will produce terrain analysis products automatically. Complex terrain graphics that take hours to produce manually can be produced in minutes on DTSS; the system is certain to significantly change the nature of the 81Q occupational specialty.

My own laboratory at USAETL is the Research Institute. Our work is long term, and is expected to make its impact in the field only after 10 to 20 years. My section is the Center for Artificial Intelligence; we develop techniques for computerized terrain analysis in the post-DTSS era. Our design for Carat responds to our idea of what this era will require.

The name "Carat" comes from Commander's Aid for Reasoning About Terrain. The "C" in Carat implies an optimistic assumption concerning the interest of commanders in our system. Under current procedures commanders do not do a great deal of detailed reasoning about terrain. Terrain analysis is a staff function performed by a terrain detachment, often under the command of a Warrant Officer. Our assumption is that as Carat technology matures computers will take over more and more of the routine work, permitting a smaller staff for planning tactical operations. In this situation, we expect some involvement of commanders with Carat-like systems, particularly in garrison and particularly in "what-if?" scenarios.

Our intent in defining Carat is to have a research program that is useful, transferable, defendable, relevant, and one that solves a real-world problem. Our first success was in initiating and co-sponsoring the U. S. Army Symposium and Workshop on Artificial Intelligence Research for Exploitation of the Battlefield Environment. The conference was held in November 1988 and the results reported in [Benton 1989]; they are useful results (some recommendations are quite detailed) but we were not given a strong mandate to develop a particular product or technique. We learned that computers are still too hard to use, hierarchical organization helps control complexity, one picture is worth a million words, the world needs more digital data, and the products we (the computing community) are delivering to the Army are still not the right ones.

At this point we took a long look at our situation and contrasted it with the situation in other artificial-intelligence laboratories, e.g. the Internal Revenue Service. The IRS fields about three new expert systems each year with no problems about finding new applications or defining new problems. We concluded that most of the readily-developed rapidly-fielded expert systems were based on verbal, analytic knowledge and that what underlies terrain analysis is a different cognitive style. The terrain analysis style is perceptual, visual, and synthetic rather than analytic. Adapting conventional artificial-intelligence techniques to this body of knowledge and way of thinking presents us with a real research challenge, since many standard techniques are based on verbal thinking and analysis. Interviewing experts on non-verbal methods might also require new techniques. (Some people call the two cognitive styles "left brain" and "right brain" after the terminology of Roger W. Sperry, who received the Nobel prize in 1981 for his innovative studies, first published in 1968).

We also surveyed related research projects and decided that our work should concentrate on *terrain*, in its military aspects. Some research programs that claim to be developing terrain reasoning are actually contributing more to research in sensor fusion and situation assessment.

More interviews with terrain teams, senior officers, and concerned civilians eventually led to a response to the challenge of the post-DTSS era; we like to present it in terms of *battlefield visualization* and *terrain reasoning*.

2. BATTLEFIELD VISUALIZATION

Combat commanders need to know as much as possible about the battlefield if they hope to control the action upon it. A way to visualize the battlefield is to use maps and photographs. One system uses paper wall maps overlayed with transparent plastic that can be written on with markers and grease pencils. It's a system with many advantages: You can pin up supplementary material, such as photos or computer-produced oblique views. You can use the overlays as a medium for communication, roll them up and take them to another van. There are usually other paper maps at different scales around that can be pinned to the wall as needed. There is enough wall space for several maps.

How can a computer, with its tiny screen, compete with this festival of cartographic luxury? Our answer will take the form of a demonstration featuring a variety of cartographic styles, perspective displays, and fast algorithms for putting information on computer screens.

Cartographic Style

Professor Nicholas Negroponte from the M.I.T. Media Laboratory claims to have seen computer displays that could qualify as OSHA violations. Certainly, the typical computer map is ugly and hard to use. We believe that our group is especially qualified to work on cartographic style in computer displays. We have access to cartographers and soldiers, and we are able to patiently produce prototype after prototype in a way that contractors would find difficult to do because of constraints imposed by their contract. We are especially interested in developing fast, standard methods for "declutter" and its opposite, "semantic zoom" -- methods for simplifying or intensifying a cartographic display. We have been informed that even experienced terrain analysts have difficulty in copying information from a 1:50000 map to a 1:250000 map. There is no standard on what to leave out.

Perspective Displays

These displays present a view of the terrain in full perspective. It's possible to change the observer position and see how the land looks from any location. The simplest type of perspective display is made from elevation data. It consists of a grid of equally spaced lines that follow the changing elevations of the earth. The result is a "fishnet" representation that can give the viewer clues about the shape of the surface but none for texture or vegetation. If aerial imagery is available however, methods such as Robertson's can be used to produce marvelous perspective pictures [Robertson 1987]. Our experience is that people want perspective displays badly; they are the most popular part of almost every demonstration. We intend to add labeling of important features, and overlaid lines indicating (e.g.) political boundaries.

Fast Graphic Algorithms

Users of computers know that if the response time is too slow the continuity of the work is lost. Maps and pictures have to be accessed and displayed quickly, or users will revert to paper maps on the wall. Our group has a special interest in scanline methods and has argued successfully for their use in remote sensing and geographical information systems as well as computer graphics [McDonnell 1989]. Using scanline methods McDonnell is able to display (on a Sun 3) a 512x512 perspective image in 30 seconds and a 1024x1024 perspective image in 2 minutes. These figures represent a speedup by a factor of 4 over the original implementation. In the research vein, we want to work more with cellular automata. McDonnell has implemented a cellular-array thinning algorithm that appears to offer promising speedups for this operation. Thinning areas to lines is a common operation in computer graphics, so this work could lead to speedups throughout Carat.

3. TERRAIN REASONING

Our group cannot agree on a definition of terrain reasoning, but we can agree about terrain analysis.

Terrain analysis is the process of identifying regions of the battlefield that satisfy the requirements of particular tactical actions. Terrain analysis goes on continually in garrison. In the field, particular terrain analysis products are produced in response to operational orders.

Operational orders for a mission may be accompanied by an acetate overlay for a map, identifying obstacles and objectives. A terrain analyst engaged in terrain reasoning uses paper maps, acetate overlays, electronic maps, aerial photographs, and collateral information from geology, forestry, and hydrology. Terrain analysis is dependent on the terrain, the mission, and the particular commander.

Terrain analysis answers questions such as "Where shall we put the command post headquarters?" that would appear to require terrain reasoning. But on computers such questions can be answered by simpler means than using expert systems. A DTSS-like system can (in a sense) answer the question by retrieving polygons from a database and performing boolean operations on them. In the case of the command post headquarters we might retrieve polygons for "wooded region", "flat region", "buffer zone surrounding a secondary road", "buffer zone behind a hill", and intersect them. All polygons in the intersection set are suitable for command post headquarters if our initial assumption is correct that the site selection depends only the area being flat, wooded, near a secondary road and behind a hill. Where does the terrain reasoning come in? It comes in formulating the query and interpreting the answer. The DTSS-like system has not really answered a question; the thought was provided by a trained human being. In more complex queries (e.g. those concerning landing zones and drop zones) the role of the human formulating the query and interpreting the output is even greater.

Our research is directed toward having the computer do more of the work, so that questions can be formulated in high-level terms and answers are presented that are concise and useful. If we are successful then the job of terrain analysis can be done with fewer people, and those people will not have to be so highly trained. Achieving this goal will contribute to the Army's objective of controlling training costs, which at present are very high.

Symbolic Terrain Representation

In order to reason about terrain, we need to represent it symbolically. Digital terrain data are typically distributed in vector or raster format. It needs to be converted to a symbolic form in order to combine it with (e.g.) doctrinal information. There is no agreed-upon way of representing terrain symbolically, although many systems have devised ad hoc methods. Our research in this area will produce, from standard vector or raster representations, standard symbolic descriptions in terms of standardized terrain features such as hills, plains, cliffs, valleys, escarpments, and abstractions such as "rolling uplands." The method takes context into account so that if the area is a desert we might identify a feature as a "dune" that would be called a "hill" in western Europe. An extension to the research would develop techniques to describe relations between terrain features such as "inside-of", "between", and "adjacent-to."

Our plan for symbolic terrain representation involves treating the digital elevation matrix like a range image and segmenting it. A natural way of segmenting terrain is according to the drainage channels that cross it and help define landforms.

The method we use for terrain segmentation is a drainage delineation program developed in our group [Seemuller 1989]. The purpose of this research was to provide an automated method for extracting a drainage network from terrain elevation data derived from aerial photographs, so that a drainage overlay could be obtained for denied areas where no database had previously existed. The elevation data Seemuller used for his experiments were obtained from stereocorrelation of digitized aerial photographs. His results compared favorably with hand-drawn networks from the same photographs. This research has been successfully transitioned to two development projects at USAETL. In Carat it will have a new application as a tool for image segmentation.

After the image is segmented, individual features can be characterized mathematically. The characterizations can then be mapped into descriptive terms for terrain. Some semantic calibration will be necessary. We need to be more exact than most textbooks are about such terms as "rugged", "difficult", "narrow" and "steep" as well as abstractions such as "rolling uplands."

Area Studies

An "area study" is an intelligence product that includes natural-language descriptions of terrain and their military consequences. Area studies are compiled from a variety of sources then put together in one book to provide the reader with the most concise and easy-to-use document possible. Making an area study is part of Intelligence Preparation of the Battlefield; it is normally done in garrison. The studies are revised periodically so they are always up to date.

Carat prototypes produce (short paragraphs for) area studies automatically. Here are some examples of sentences similar to those that our system will produce:

(1) "The high mountains, deep valleys, and forested areas make northern Zalexico ideal for close air support because there is cover and concealment for nap-of-the-earth flying".

(2) "The short fields of fire and observation distances necessitate assigning small defensive sectors to defending units, thus requiring large numbers of troops to establish a position of defense. The principal weapons employed in this area are small arms, grenades, LAWs, claymores, and mortars."

(3) "The eastern part of the study area is undulating to rolling. The landscape is shaped by chains of hills, (average height 400 meters) and sandflats with uniform local relief in the south and broken local relief in the north. The terrain is gently rolling."

(4) "Visibilities, observations, and fields of fire are satisfactory (up to 1500 meters) throughout the area."

(5) "Rolling hills and ridges having relief up to 800 feet and altitudes as high as 2900 feet are generally unsuitable for movement. These hills make up 50 per cent of the study area."

The examples above were generated by people so that the style is better than we can expect from Carnt. Some of the examples require geographical information systems to give evidence of "forested", and a DTSS-like system to compute the visibilities, observations, and fields of fire before forwarding them to an inferential module that will conclude they are "satisfactory." The first and second examples show how doctrine can be combined with terrain information to produce a recommendation for the commander.

Combining Evidence

Some of the examples above required combining evidence from more that one computer program, but the combining of evidence was fairly straightforward. It is possible however that if conflict were to break out in an unexpected location, scraps of evidence would have to be hastily combined in nonstandard ways in order to produce information about the country and the probable fields of conflict.

There is actually a geographical tradition for inferring terrain from collateral sources. If all the folksongs of Zalexico are sea chanties and the national dish is fish stew, we can conclude that the Zalexican coastline has an abundance of natural harbors. This inference wouldn't be made by a computer because it wouldn't have data on food and music, but there are other collateral sources. Geomorphologists for instance have extensive data on rocks of the world [Snead 1980]. Large sections of South America, Africa, and Asia have not been studied in great detail, but for much of the world there is data on the composition of rocks. Sometimes it is possible to make inferences of military importance: for example if the rocks in a particular area are subject to granular decomposition, then the disintegrating rock will prove hazardous to the treads of tanks.

We believe that one type of data that is quite rare now will be abundant in the future: that is elevation data from the stereocorrelation of aerial or satellite photographs. Determining elevation by stereocorrelation is very difficult and sometimes impossible. Pictures of clouds, deserts, and snowfalls are too uniform to correlate and periodic patterns, such as orchards, and be correlated only with great difficulty. But techniques are improving so rapidly that we assume elevation data from stereocorrelation will be common within 15 years.

For our research we use elevation data produced in the Research Institute of USAETL using the *Match* program [Norvelle 1981]. This same program produced the elevation data for Seemuller's drainage research refered to above. We have produced a section of elevation data from Fort Hunter-Liggett in California and have made it the basis for preliminary experiments.

Match can produce data with elevations spaced at any increment down to the pixel size of the image. Most applications appear to require elevation spacing in the range of 10 to 100 meters. The correlation algorithm gives the elevation of whatever it "sees", and in a wooded area the elevations are of the treetops, not the ground. As the spacing gets closer, the terrain profile traced by the correlation algorithm gets more irregular, but this is not noise; it is the true irregular surface of the earth. For drainage delineation better results are obtained if the data is smoothed. However, when elevation data from stereocorrelation can be combined with other information (for example the intensity image of the photograph) then it could be possible to obtain a realistic estimate of the microrelief – the ditches and hedgerows that are too small to be recorded on a contour map and yet are of military importance.

We hope to develop techniques for combining geomorphological and stereocorrelation data in such a way as to provide the commander with a visualization not only of the terrain but the micro-terrain, and so make unfamiliar territory as familiar as it can be without an actual visit.

Hierarchical Route Planning

Some of the questions that terrain analysis can answer have the form "How do I get from *POINT A* to *POINT B* given *CONDITION*." Here *POINT A* and *POINT B* are places and *CONDITION* could be anything at all, for example:

> "...the steep hills and narrow valleys that separate *POINT A* from *POINT B*.
>
> "...that it's rained 2 centimeters in the last 24 hours."
>
> "...the disposition of opposing forces."
>
> "...they just blew up The Bridge Over The River Kwai."

Very often most of the information needed to find the paths to an objective are present in a cross country mobility map, but it is not easy for even a trained analyst to quickly determine multiple optimum routes. This is especially true if collateral information is to be taken into account.

Finding optimum routes on a computer is in general subject to a combinatorial explosion in the number of steps required to a solution as the number of potential routes increases. However John Benton from our group has devised a Hierarchical Route Planner which ingeniously uses two planners in a hierarchy to control the complexity of the problem [Benton 1988]. A special advantage of Benton's program is that it can provide multiple non-competing paths for solutions to problems where troops, equipment, and supplies are required to move roughly in parallel but without traffic jams.

A reworked and enhanced route planner will become a component of Carat. Techniques developed for the route planner can also be adapted for other faster-and-better terrain analysis methods, for example discovering mobility corridors and choke points. A geographical information system will provide the mobility map that the route planner needs to work on. The routes found by the planner are represented symbolically so they can be used for further inference, e.g. as part of a program for weapons siting.

4. PROGRESS

Carat is a new program with only preliminary results. A top-level route planner has been implemented and demonstrated. Fast algorithms for perspective display have been devised, improved and demonstrated. A cellular-array thinning algorithm has been programmed and tested. It is currently being evaluated as a means of characterizing contours. We have collected maps and terrain studies for Fort Hunter-Ligett to go with our stereocorrelation data for the same area so that we have ground truth to evaluate our methods. We have a program that fits least-square lines to terrain profiles, and have used it to characterize the Fort Hunter-Ligget terrain as "mountainous." As a residue from a contract on Minefield Site Prediction we have the Quilt geographical information system running on one of our computers. We are evaluating it as a possible front-end program to some of the Carat components.

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OPTIMUM ROUTE EVALUATION USING CAMMS

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ABSTRACT/BACKGROUND

For several years cross-country mobility maps have been created utilizing the Condensed Army Mobility Modeling System (CAMMS). These maps would show the maximum speed which a vehicle could attain in each digital terrain description (terrain unit). This predicted map would be useful in comparing the performance of vehicles or as an aid in manual route selection. Recently, a computer model has been developed to select optimal routes using a map of mobility speed predictions produced by the CAMMS. This model utilizes heuristic search methods to select optimum routes of user determined widths between user designated starting and goal locations. A second computer model has been developed to evaluate a route for several types of vehicle formations.

DEFINITIONS

The following are definitions of terms used in the paper:

a. Arc. The representation of the application of an operator in a search tree. Arcs connect nodes to their successors.

b. Artificial Intelligence (AI). The part of computer science concerned with designing intelligent computer systems, that is, systems that exhibit the characteristics we associate with intelligence in human behavior (Barr . . Feigenbaum 1981).

c. Blind search. A search in which the order of the search is arbitrary and is not influenced by real world knowledge of the search space.

d. Forward reasoning. The application of operators to bring the situation forward from its initial state to one satisfying a goal condition.

e. Heuristic. Knowledge of the problem domain, which helps improve problem solving performance.

f. Node. The states, as they are represented in the search tree, created by operators as the search proceeds.

g. Operators. A set of rules that transform the problem from one state to another.

h. Ordered search. A search routine that always selects the most promising node as the next node to expand.

i. Search tree. The tree that is constructed and grows as the search proceeds.

j. State-space representation. A problem solving system that uses forward reasoning and whose operators each work by producing a single new object in the data base.

k. States. Data structures which show the condition of the problem at each stage of its solution.

SELECTION METHODOLOGY

The automated route selection program was developed using an AI algorithm referred to as A* (Barr and Feigenbaum 1981). A* is an ordered state-space search which utilizes a heuristic to decrease the number of nodes which must be expanded, while still finding an optimal solution. An evaluation function in the A* algorithm involves two parts. One part computes a value weighing the cost of the path from the start node to the current node. The second part estimates the cost of a path from the current node to the goal node. The first part of the evaluation function used in the search to solve the problem of finding the best route involves the use of the following cost function:

$$\text{WEIGHT} = \text{LENGTH}/\text{TEMP}$$

where

WEIGHT = Cost associated with the grid cell in question

LENGTH = Distance traveled across a cell (miles)

$$\text{TEMP} = \cfrac{1}{\cfrac{\sum_{1}^{J} \cfrac{1}{\text{SPEED}}}{J}}$$

where

J = Number of grid cells that the modeled formation will cover at one time

SPEED = Predicted speed (mph) for each cell that the formation covers at one time

This weight is computed for each possible grid cell in the mobility terrain data base upon which the modeled formation could be centered. This weight factor is utilized to weigh slower speeds and NOGOs (0.1 mph) more heavily than higher speeds and thus facilitate their avoidance. This weight is summed for each grid cell which a path crosses in traveling from the starting cell to a node (cell) in the search tree and this sum is referred to as g*.

Slope direction is utilized by A* in the selection of the speed utilized in the computation of WEIGHT. This modeling of the effects of slope on route selection requires a slope aspect map. Each grid cell in the slope aspect map matrix contains a compass direction in which the slope faces. These compass directions are classed by the program into the eight possible directions of movement when traveling between cells on a gridded map matrix. These classes are shown in Figure 1. When movement across a grid cell is in the same general direction as the slope aspect, then travel is modeled as down-slope. For example, if the slope aspect is in direction 6, then directions 5, 6, and 7 would be down-slope; directions 1, 2, and 3 would be up-slope; and directions 4 and 8 would be across-slope. Forward reasoning is utilized by the program, since search from the goal to the start would require the reversal of all slope directions to ensure the selection of the best route.

The second portion of the evaluation function used in the search to find the best route involves the use of the following heuristic:

$$h^* = DIST/MAXTMP$$

where

h* = Absolute minimal sum of weights which the search could possibly find between the current cell in question and the goal cell.

DIST = Euclidean distance from the grid cell in question to the goal cell.

MAXTMP = Maximum value of TEMP computed for any cell on the mobility terrain data base.

This heuristic satisfies the admissibility condition, which requires that h*(n) is less than or equal to h(n), which is the actual cost of an optimal path from cell n to the goal cell. If h* satisfies this admissibility condition and if all arc costs are positive and can be bounded from below by a positive number, then A* is guaranteed to find a solution path of minimal cost if any solution path exists. The entire evaluation function (f*) for a cell n in the search is given by $f^*(n)=g^*(n)+h^*(n)$.

The basic A* search algorithm (Nilsson 1971) was implemented for optimal route selection as follows:

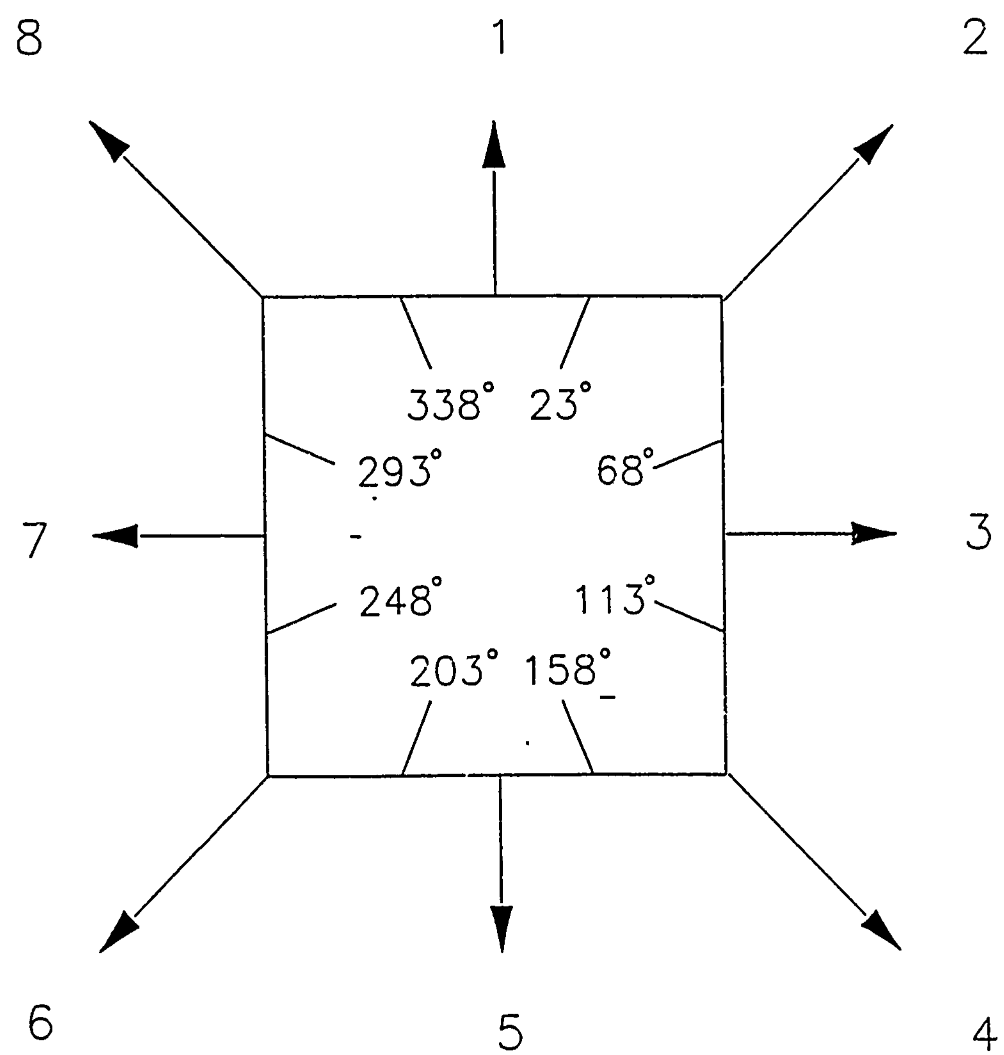

Figure 1. Slope aspect classes

1. Put the starting grid cell on a list, called OPEN, of untraveled grid cells. Compute an f* value and associate it with this origin grid cell.

2. If OPEN is empty, exit with failure; no solution exists.

3. Select from OPEN a grid cell (GXY) with the lowest associated f* value. Remove GXY from OPEN and place it on a list, called CLOSED, of traveled grid cells.

4. If GXY is the goal cell, exit with the solution path obtained by tracing back through the pointers; otherwise continue.

5. Expand grid cell GXY, creating the eight adjacent successor grid cells. For every successor cell SXY of GXY:

a. Compute an f* value for SXY.

b. If SXY is neither in list OPEN or in list CLOSED, then add it and its associated f* value to OPEN. Attach a pointer from SXY back to GXY (in order to trace back a solution path once the goal is reached).

c. If SXY was already on either OPEN or CLOSED, compare SXY's new f* with the f* previously associated with SXY. If the new f* is less, then

(1) Substitute the new f* for the old f*.

(2) Point SXY back to GXY instead of its previous predecessor.

(3) If grid cell SXY was on the CLOSED list, move it back to OPEN.

6. Go to Step B.

A map of omni-directional speeds (i.e., an average of up-, across-, and down-slope predicted speeds) for the M1A1 tank in the Lauterbach quad (L5322) in the Federal Republic of Germany is shown in Figure 2. A one kilometer wide route selected on the Lauterbach quad by the A* algorithm for the M1A1 tank is shown in Figure 3. Figure 3 shows both the selected avenue and the cells which were examined during the search.

The A* algorithm may be modified by making h* zero. This would cause the algorithm to be reduced to a more basic ordered state-space search algorithm. Obviously by not computing h*, many floating point computations will be avoided in the computation of f*, though the number of cells which must be examined in order to find the optimal solution will increase. Figure 4 shows the one kilometer wide route selected by this method and also shows which cells were examined during the search. The amount of Central Processing Unit (CPU) time used by each method on a VAX 11-785 was 605 seconds for A* and 601 seconds for the basic ordered search. Of this time 531 seconds was used to load data files and compute the weighted averages for each cell on the entire map. Since the ordered search does not use the heuristic and thus does not need to know the lowest computed weight on the map, f* values may only be computed for cells involved in the search. With this modification the program found the solution while using only 473 seconds of CPU when given the same

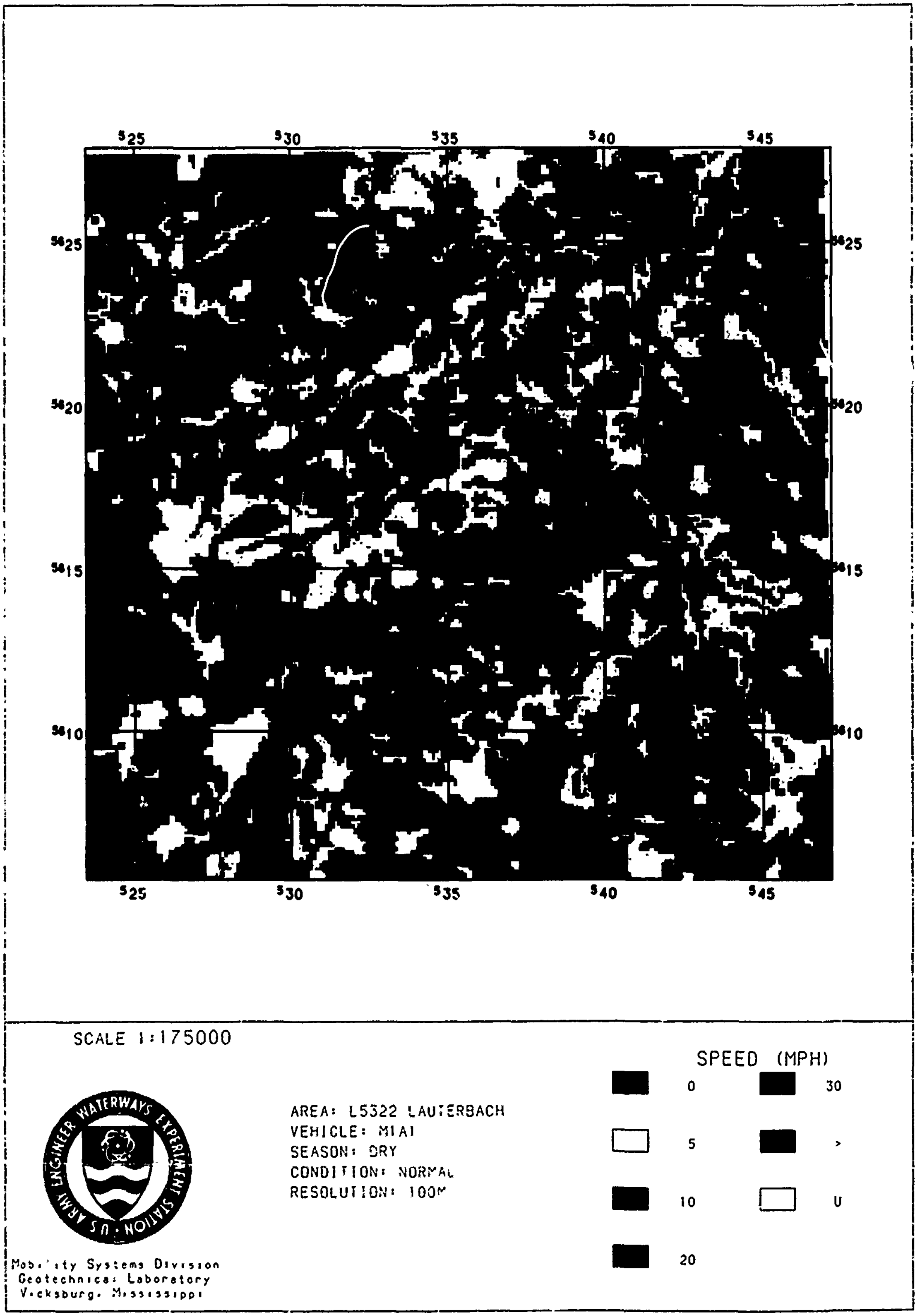

Figure 2. Omni-directional speed map

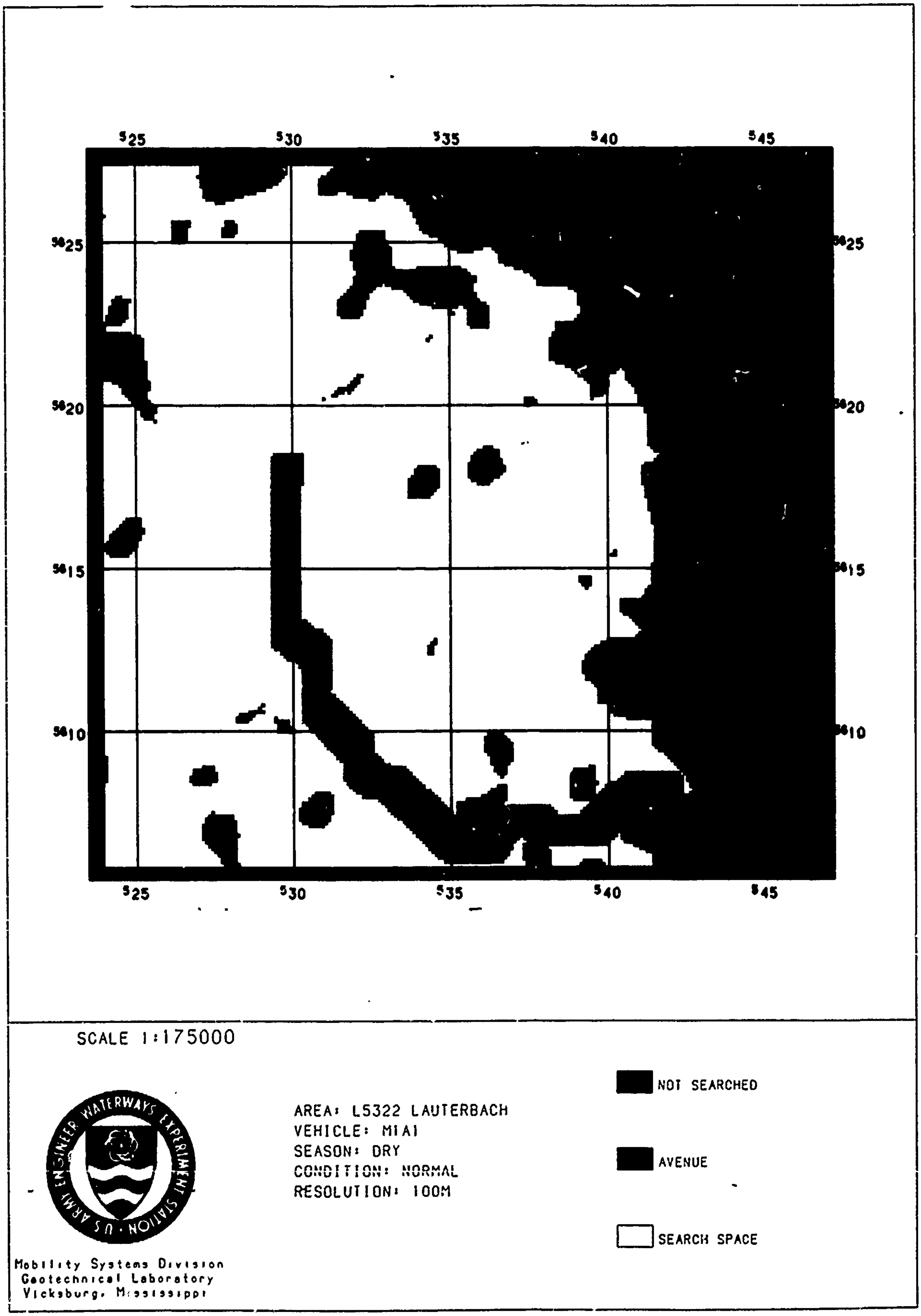

Figure 3. Route selected by A*

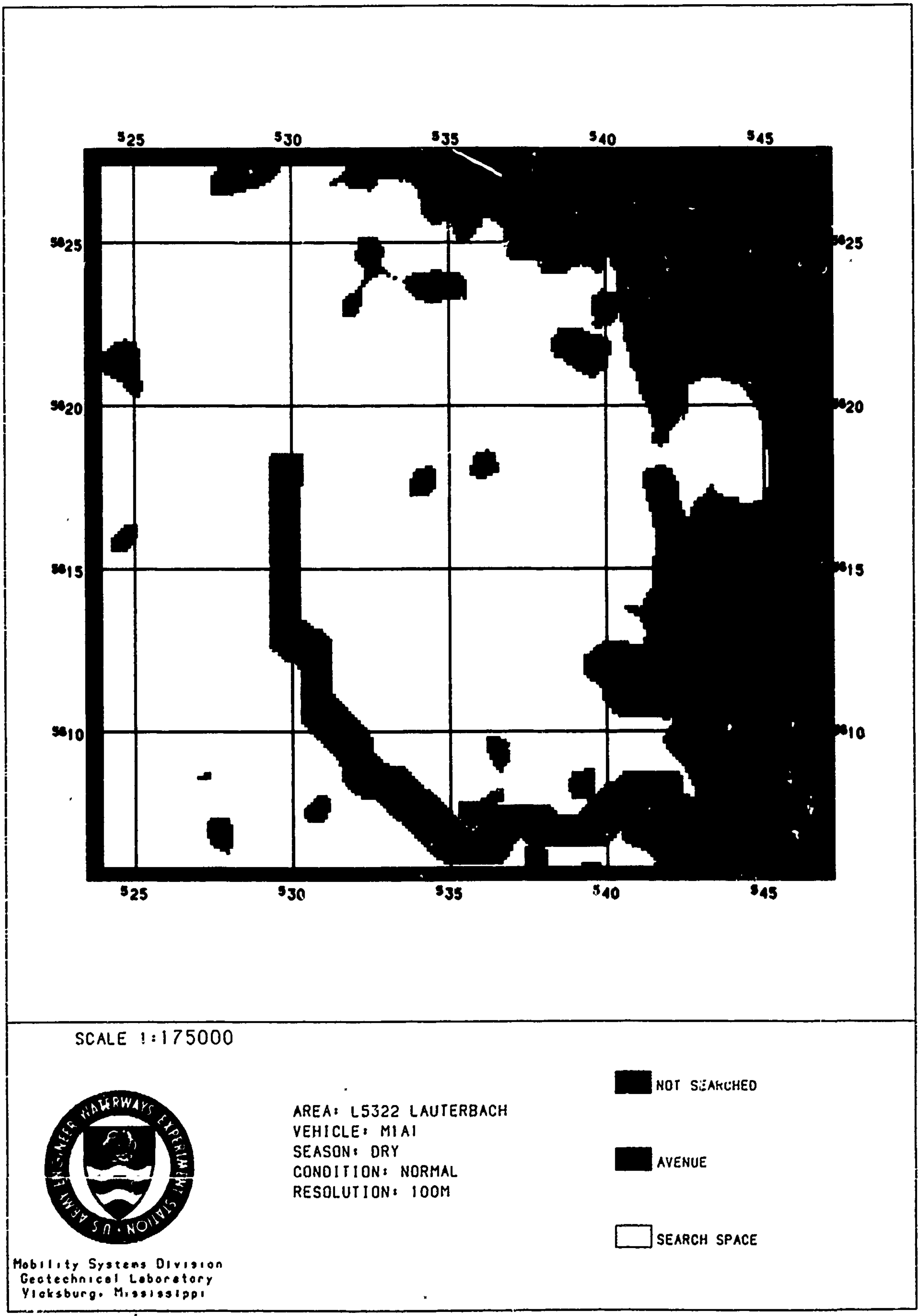

Figure 4. Route selected by ordered search

Analysis of Tactical Courses of Action Using Structured Procedures and Automated Aids[1]

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Introduction

Current doctrine for tactical staff operations involves performing an estimate of the situation (see Figure 1). The format for the estimate has met the test of time, as it has been used by the U.S. Army (with modifications) since 1910 (War Department) (see Table 1). However, as the violence and pace of battle increases and as information processing technology is applied, the specific procedures for the estimate are worthy of re-examination. Of issue is whether current procedures for the estimate process match the conditions of the modern battlefield. Emerging evidence suggests that there is a disconnect between how the estimate is actually done and the guidance indicating how it should be done.

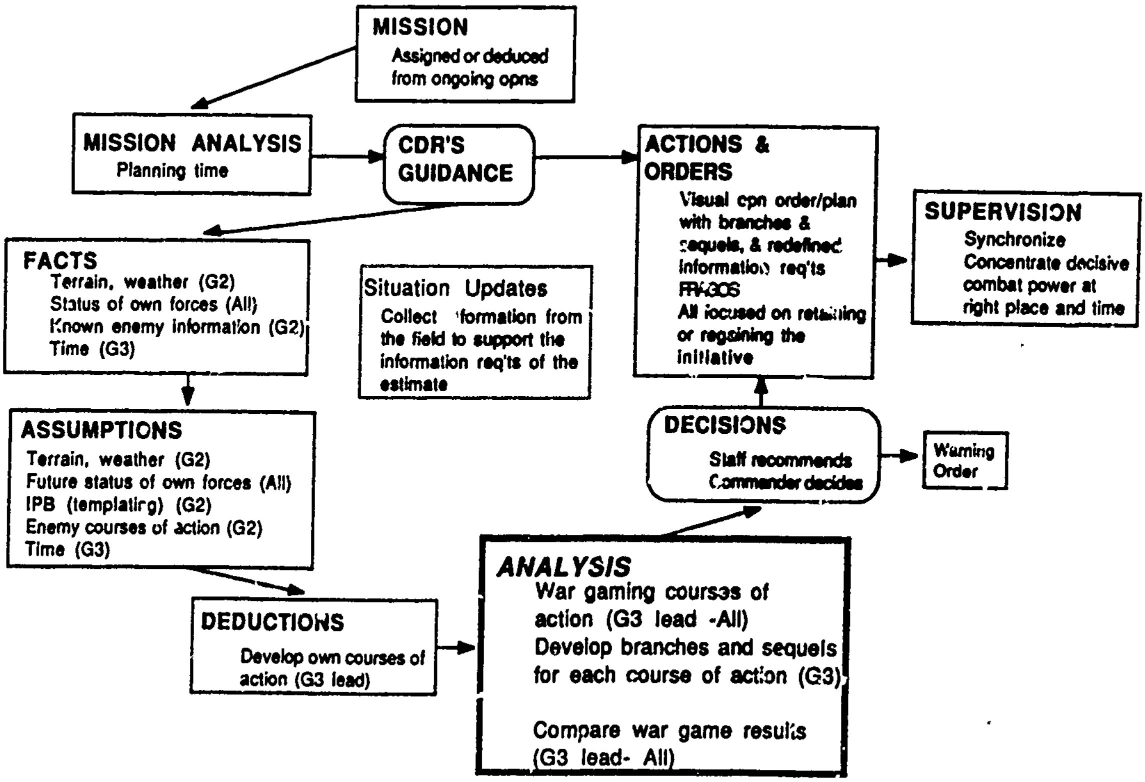

Figure 1. Command estimate (CGSC ST 100-9).

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Table 1.

Format of the Estimate.

FM 101-5, 1932	FM 101-5, 1984
1. Mission	1. Mission
2. Opposing Forces	2. Situation and COA
a. Enemy forces	a. Considerations
b. Own forces	(1) Area of operations
c. Relative combat strength	(a) Weather
3. Enemy Situation	(b) Terrain
a. Plans open to enemy	(c) Other factors
b. Analysis of enemy's plans	(2) Enemy situation
c. Enemy's probably intentions	(a) Dispositions
4. Own Situation	(b) Composition
a. Plans open to you	(c) Strength
b. Analysis of plans	committed
b. Analysis of plans	reinforcements
5. Decision	artillery
	air & NBC
	other
	(d) Significant activity
	(e) Peculiarities & weaknesses
	(3) Analysis of COA [same as (2) above]
	(4) Relative combat power
	b. Enemy capabilities
	c. Own COA
	3. Analysis of COA
	a. List of enemy capabilities
	b. Analysis of each COA vs. each enemy capability
	4. Comparison of COA
	a. List advantages & disadvantages of each COA
	b. Conclusion on best COA
	5. Decision (Recommendation)

Performance on the estimate of the situation often does not meet expectations. Some of the observed issues and implications include those identified below. These issues come from observing field exercises (e.g. Thordsen, Glaushka, Klein, Young, & Brezovic, in publication), laboratory experiments (e.g. Michel & Riedel, 1988), classroom exercises, and tactical decision making literature.

(a) The process is not followed. (In many cases it may not be appropriate; procedures for a novice decision maker or new staff are not necessarily appropriate for experts.)

(b) The sequence of steps is not always practical. (The estimate is presented in doctrinal materials as a sequential process, yet the dynamics of the situation imply iterations, feedback and feed forward links.)

(c) Sufficient time is usually not available to complete a thorough estimate. (The detail of the estimate has grown along with analytical techniques for planning and decision making, while the time to complete the estimate is decreasing.)

(d) Abbreviated procedures are not standard. (Little guidance is provided on how to tailor the process to fit within varying, available times.)

(e) Human information processing biases and limitations affect the process. (Human decision making biases include strategies such as recent information treated as the most valid, filtering of information to fit a preferred or initial assessment, and "group think".)

(f) There is little confirmed basis for battle outcome predictions in the analysis step. (War-gaming relies heavily on visualizing the battle, but few rules or experimental factors are provided to shape war-gaming judgments.)

There has been surprisingly little research which attempts to identify tactical decision making problems, diagnose and offer solutions to the problems, and evaluate candidate enhancements. This research to develop effective staff procedures is significant now because of the Army's desire to use automated information processing to support the planning process. As computers are looked at to increase the thoroughness and speed of planning, it becomes even more important to prioritize where enhancements should be applied (Carter, Archer & Murray, 1988) and to determine effective, standard procedures which may be accommodated by automated support.

Purpose

The research reported in this presentation has multiple objectives. The major objective is to determine the relative effects of a structured step-by-step process for course of action analysis versus utilizing a process based primarily upon the military background and experience of the participants. A second major objective is to investigate the relative effects of providing automation support to the manual, structured process. This paper presents initial results from an experiment in progress on the effects of (a) guidance for following predetermined estimate procedures and (b) automated information processing aids on performance of the estimate process.

Procedures

In the experiment a team of two officers portray members of a G3 (operations) planning staff. They are responsible for analyzing two tactical courses of action (COA). They start with background situation information and are given the Division Commander's intent for two COA in his guidance. The result of the task is a recommendation to select one of the COA and the rationale for the decision. Steps for the task are summarized in Table 2. The tactical scenario takes place as an offensive operation of a mechanized infantry division in a Western European environment (Fallesen, Michel & Carter, 1989). The exercise teams came from Combined Arms Center officers who had been trained in staff operations and the estimate. The research is conducted in the Army Research Institute's command and control human performance laboratory. So far three teams (from a target of 18) have completed the day long exercise, one team in each of the three experimental conditions:

1. Unspecified, manual. Only the end product of the COA analysis is requested from the officers (i.e., decision, rationale, and concept of operation). The procedures to conduct the analysis are unspecified. Scenario materials are available in printed form.

2. Structured, manual. The steps of the COA analysis are specified in work sheets (annotated with instructions) and the officers are instructed to follow each step. Printed scenario materials are available.

3. Structured, automated support. The steps of the COA analysis are specified in worksheets, which also indicate how to use two prototype computer systems to complete the task (Tactical Planning Workstation and Course of Action Assessment Tool [COAAT]). The computer tools support information display (text and graphics) and retrieval, report production, and other task aids.

A moderator (experimenter) provides training appropriate to each condition and facilitates the conduct of the exercise. The operation briefing requires the estimate to be completed in about 4 hours, and the moderator intervenes, as necessary, to ensure that the task is completed within 4 hours and 45 minutes. Performance Data are collected from the completed workbooks and through direct observation, video and audio recordings, and automatic data capture when the Tactical Planning Workstation and COAAT are used.

Hypotheses, Measures and Scoring

The critical experimental question pertains to decision quality:

In what condition has the analysis been most thoroughly performed?

It was hypothesized that the structured-automated condition would produce better solutions than the unspecified-manual condition and the structured-manual condition. Also it was hypothesized that the structured-manual condition would produce better solutions than the unspecified-manual conditions.

The primary dependent measure of the study addresses quality. Quality of analysis was measured by comparison of how closely the experimental participants' products matched those developed by a panel of experts. Quality measurements are made for steps 2, 4, 5, 7, 8, 9, and 10 in the two structured conditions. In the unspecified-manual condition the lack of observable distinct procedures limits quality measures to steps 9 and 10 (see Table 2).

Other measures are being used to aid in the diagnosis of results, to describe the details of the process, and to elicit knowledge and models from officers trained in staff operations. These supporting measures include:

workload assessment	demographics
information use	time management skills
war-gaming style	team dynamics
understanding of the situation	decision style
human factors of computer tools	decision strategy
task procedural questionnaire	decision characteristics
individual demographics	use of source media.

Initial Results and Discussion

At the present time the results can only be looked at to provide initial indications on the experimental procedures. There are not normative data on the measures so the data can be treated only qualitatively. Statistical comparisons certainly are not warranted.

The three teams were assigned to the three conditions randomly. There were some differences between the teams in terms of background and experience. In ratings of team dynamics, four experimenters independently rated the unspecified-manual team's knowledge of task procedures and tactics as poorer than the other two teams. Differences between teams may be responsible for any apparent differences in performance, rather than the independent treatments of structure and automation. The small sample size is worthy of preliminary consideration in the sense of a case study approach and a report of research in progress.

Structure and Decision Quality

Structure was imposed on the participants in the structured-manual and structured-automated conditions through the use of successive work sheets and positive experimental control. Participants in the unspecified-manual condition were not constrained to a specific planning structure to produce the required operation estimate, however, this does not imply that their analysis was without structure. The participants in this case are free to use an analysis structure of their own choosing. The team in the unspecified-manual condition referred to doctrinal publications (specifically FM 101-5 and CGSC ST 100-9) for guidance of intent. They did not follow the procedural guidance for individual steps of the analysis. For example, the unspecified-manual team did not perform any war-gaming of objective factors.

For step 9, justify the recommended COA, the team in the unspecified-manual condition considered 7 of 15 justification factors agreed upon by the expert panel. Of the 7, 2 were considered advantageous for one COA while the expert panel considered them as advantageous for the other. This team chose the non-preferred COA and their overall score was 17 out of possible 100 points for this step. The structured-manual team considered 5 of the 15 expert factors, matching 3 of the 5. They did chose the preferred COA and received an overall score of 60. The structured-automated team considered 8 of the expert's 15 factors, matched on all 8, and selected the preferred COA for an overall score of 77.

Identifying Facts

Both structured teams exhibited a weakness in identifying operational facts (step 2), scoring only 25 and 17 out of 100 possible points.

Arraying Forces

Both the structured teams had low scores (0 and 10) in step 4 for arraying forces for each COA. Both teams failed to provide sufficient combat power to the main attack to ensure at least a 50 percent chance of success. They made related errors which included allocating field artillery to the reserve, allocating excessive combat power to the reserve, failure to employ all available combat power, and failure to allocate attack helicopters to main or supporting attacks.

Table 2

Steps of course of action analysis and initial performance data (based on single cases for each condition).

STEP	TASK	NOTES	QUALITY SCORE U-M	QUALITY SCORE S-M	QUALITY SCORE S-A
1	Select COA for analysis	Provided in Cdr's guidance			
2	Review area of interest and gather facts (METT-T)			25	17
3	List assumptions	Provided to control experiment			
4	Array forces for each COA			0	10
5	Determine critical events			82	73
6	War-game critical events for each COA	Scored with step 7			
7	Aggregate and scale battle results for each COA			0	33
8	Compare COA			50	100
9	Justify recommended COA	Primary criterion for exp. comparison	17	60	77
10	Develop concept of operation	Develop maneuver & fires taskings	56	25	50

U-M - Unspecified-manual
S-M - Structured-manual
S-A - Structured-automated

Quality is computed by comparing the worksheets from the teams to the bench mark solution of the expert panel. Algorithms are used to compare the closeness of the match on various attributes in each step. Each step score can range from 0 to 100.

Selecting Critical Events

The two structured teams scored high (82 and 73) on the selection of critical events (step 5) for both courses of action.

War-gaming

A notable weakness is indicated by the scores (0 and 33) on war-gaming (step 6) and assessing battle results (step 7). The scoring technique did not require exact matches with the battle results calculated by the expert panel but did require that relative results for the two COA did match the panel. The observed weakness is probably more indicative of the lack of procedures or doctrinal guidance to provide estimation techniques for engagement outcomes than it is a failure of the participants.

Compare COA

The procedures to compare COA (step 8) required the two structured teams to address qualitative, subjective measures (e.g. risk, surprise, simplicity, flexibility, etc.) and to weight and scale the assessments on both subjective and objective measures for each COA. The structured-automated team matched the expert solution and obtained a score of 100. The structured-manual team did not match the experts within the bounds permitted, and matched only the subjective measures to obtain a score of 50.

Information Usage

The analysis of information usage from the structured-automated case indicated that 59 of the 121 (49%) significant information items (as judged by the scenario authors) were discussed. Nine items that had not been previously identified as significant were discussed by the team. Of these 68 items, 44 were only discussed once or twice, while 9 items accounted for 36% of the discussions. The enemy second echelon force was the most frequently discussed item during the planning session.

Understanding of the Situation

To test the degree of understanding of the tactical situation and scenario a 32 item multiple choice test was administered after the exercise to each of the participants. There were eight questions on each of the areas of mission, enemy, own troops, and terrain. The results for the three teams indicated relatively poor performance. The unspecified-manual team answered 42% of the questions correctly, the structured-manual team had 63%, and the structured-automated had 55%. For all six participants tested to-date, there was less than 40% correct answers on mission and enemy, while terrain and own troops questions were answered correctly 68% of the time.

Use of Media

There was concern that the structured-automated team might not use the Tactical Planning Workstation and COAAT, however, this did not appear to be the case as it was estimated that they used the automated tools from one half to two thirds of the time. The structured-manual team used the paper maps and overlays the most, followed in order by the situation-scenario text materials, workbook, and reference publications. The unspecified-manual team used the situation-scenario most frequently, followed by the reference materials, paper maps, and workbook.

Utilization of Findings

The findings from this research are expected to have significant impact upon the improvement of procedures of tactical decision making and the development of task and decision aids to enhance the work of combat staffs. These findings will provide critical information to two important Army initiatives.

One of these is the standardization of all command posts from battalion through corps. This research will have an impact on the standardization of functions for the planning cell of the command posts. Upon completion of all data collection we will have a better understanding of the limitations of current procedures. We will know how closely the structured procedures can be followed and how closely the structured procedures are followed when they are not specified. We will have a better indication of the advantages and disadvantages of structured techniques for tactical decision making, e.g. scaling and aggregating attributes in COA comparison.

A related initiative is the development and fielding of tactical computers to support command and control. The assessment of soldiers using automation concepts will assist in the specification of requirements for Army Tactical Command and Control Systems (ATCCS). We are determining the extent of use of various tools, such as map and overlay data, and obtaining soldier feedback from hands-on use. User comments combined with performance and workload data will be instrumental in helping to specify not only what the user performances are but what provides a performance enhancement.

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1. This research is the result of the effort of many people involved in various aspects of the development of the facility and execution of the study: Dr. Sharon Riedel, Dr. Stanley Halpin, MAJ Edward Sullivan, SSG Ron Strickland (all of ARI), Dr. Robert Hamm (National Research Council Fellow), Mr. Paul McKeown, Mr. Bruce Packard, Mr. James Flanagan, Mr. Steve Masterson, Ms. Laura McClanahan, Mr. Glen Ross, Mr. Richard Zarse, Dr. Mark Archer, and Dr. Mike Fineberg (all of SAIC). Acknowledgement also goes to the officers from the Combined Arms Center who served as participants and experts in this research.

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TITLE: Command and Control Upgrades to the US Army Concepts Analysis Agency's Force Evaluation Model (FORCEM)

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ABSTRACT:

The US Army Concepts Analysis Agency, as part of a concentrated effort to upgrade the state of its primary theater-level model -- FORCEM, has chosen to develop a benchtest model to explore alternative representations to the command, control and maneuver portions of the model. The design effort (hereafter referred to as the benchtest) is programmed in Simscript II.5 on personal computers.

The driving motivation of the benchtest's designers was to abstract, in as realistic a fashion as resolution and structural constraints of the parent model would allow, the major missions and maneuvers of US and Warsaw Pact forces. To measure the impact of force structure changes on force capability and requirements, we must model a minimum set of operations that are fully expected to be used by the operational planners on each side.

From the US perspective, this requires a thorough look at the implications of AirLand Battle doctrine and the missions that will require execution at the division level. Thus, we found it imperative to represent both static and mobile defensive operations by including in the division's mission list: defense, delay, withdraw, counterattack, and relief operations. These tactical missions are tied together by a command and control decision-making process at the Corps level which prioritizes vulnerabilities (on either side) as they occur and chooses a response dependent on the urgency of the situation and the availability of friendly forces.

The Warsaw Pact forces attack in echelons to capture immediate and subsequent objectives. Soviet norms and planning algorithms are used to deploy the forces for the initial attacks, and situations are allowed to develop that result in Warsaw Pact forces breaking through the defender's MPR forces. The design also provides the flexibility to allow the follow-on forces to identify and exploit the successes of the first echelon, as well as conduct envelopment and bypass operations in the attack.

In both cases, the divisions operate as independent entities executing missions assigned by the higher headquarters. A

library of utility routines has been developed that simplifies the execution of the operations and allows for automatic updating of unit objectives. Additional, extensive use of input parameters makes the development and modification of scenarios relatively easy for the user and provides for flexibility in testing. The result is an abstraction that resembles the fluid battlefield of maneuver warfare more accurately than the current version. Therefore, the model shows some promise in analyzing the effects of ability, synchronization, and depth in combat operations.

Throughout development, the use of graphics has enhanced the speed and quality of the work while also serving as a powerful tool to use in conducting periodic updates for management and other interested parties. A graphic demonstration will serve as a focal point of the presentation.

No Paper Provided

STUDY PLAN ADVISOR (SPAR)

Ms. Diane M. Schuetze
U.S. Army Logistics Center

Abstract. Study plans identify how a study will be conducted to accomplish stated objectives. A good study is a direct result of careful planning and problem analysis during the study planning stage. Study planning is a learned art where experience is the best teacher. SPAR aims at capturing this expertise and provides guidance, examples and tutorials to a variety of users. Artificial Intelligence techniques in use with SPAR include knowledge engineering sessions with experts and formulation of rules capturing both regulatory guidance and expertise, the heuristic "rules of thumb." SPAR use can range from complete study plan guidance for novices to specialized module building by accomplished study planners in cases where regulations may have changed, or areas with which the planner is relatively unfamiliar. One of the most difficult challenges in developing SPAR is catering to this wide variety of backgrounds and needs.

Background. Development of a system to assist study directors with the study planning process was requested by the TRADOC Analysis Command (TRAC) to capture the expertise behind successful studies and make it available to novice planners. A tool to lead new or "rusty" planners through the study planning process would greatly improve the quality and efficiency of Army studies. Since large and small scale studies are conducted throughout TRADOC, TRAC requested a tool which would be easily exportable and run on existing hardware. Our plan of attack, therefore, focused upon a flexible software system utilizing standard IBM-compatible personal computers (PC's).

Scope. As with most large-scale processes, the problem is most approachable when broken into small, digestible portions. Army studies must be planned for all concept based requirement areas and for all types of studies from an abbreviated analysis (AA) through a full Cost and Operational Effectiveness Analysis (COEA). The concept based requirements approach includes studies in the areas of concept, force structure, training, materiel, management information systems, personnel and leadership development. Our initial effort focused on the conduct of an abbreviated analysis in the materiel arena since the majority of studies conducted under the purview of the TRAC element located at Fort Lee fall into this category. This facilitated a close working relationship between the knowledge engineer and the subject matter experts. An abbreviated analysis follows the same logic as a more extensive study but requires less detailed analysis.

Study Logic. TRADOC organizations perform studies to identify and compare alternative solutions to specified problems. Each study needs a detailed study plan that ensures the study addresses all relevant concerns and uses the proper analytic techniques. Often an analyst not experienced in conducting studies has difficulty developing a timely and proper study plan. A good study plan is the result of a careful process which examines all pertinent facets of the problem. Each issue involved should be clearly addressed and traceable from identification of the associated essential elements of analysis (EEA) to the timespan required to accomplish all required actions. **Figure** I shows the logic "chain" between the major elements of a study. For example, the sometimes broad issues raised by the study tasker are researched and modified, if necessary, to identify the specific objectives of the study. Essential elements of analysis (EEA) must be identified for each objective. The EEA are the questions such as operational effectiveness, impact, and cost which must be answered in order to accomplish the objectives of the study. Alternative systems under consideration which address the outlined objectives must be identified. Moving along the chain, measures of effectiveness (MOE) must be determined for each EEA. MOE's show the degree of attainment in quantitative terms of the stated objectives for all alternatives being considered. A cross-check of all MOE's to EEA's should reveal that each EEA has at least one MOE or other means of evaluation. The culmination of the planning phase and final link of the chain is selection of an appropriate methodology for meeting each of the study objectives. A milestone chart or timeline can be constructed at this time based upon the methodologies to be used and number of alternatives under consideration. Adequate time must be planned to accommodate resource limitations, deadlines, inputs and approvals required. The critical study path should be built based upon what must be done and when, the ordering or precedence of taskings and how much time to allow for individual actions.

AI Approach. Given the amount of experience required to construct a good study plan, an expert system approach offered

STUDY PLAN ADVISOR
(SPAR)

STUDY LOGIC:

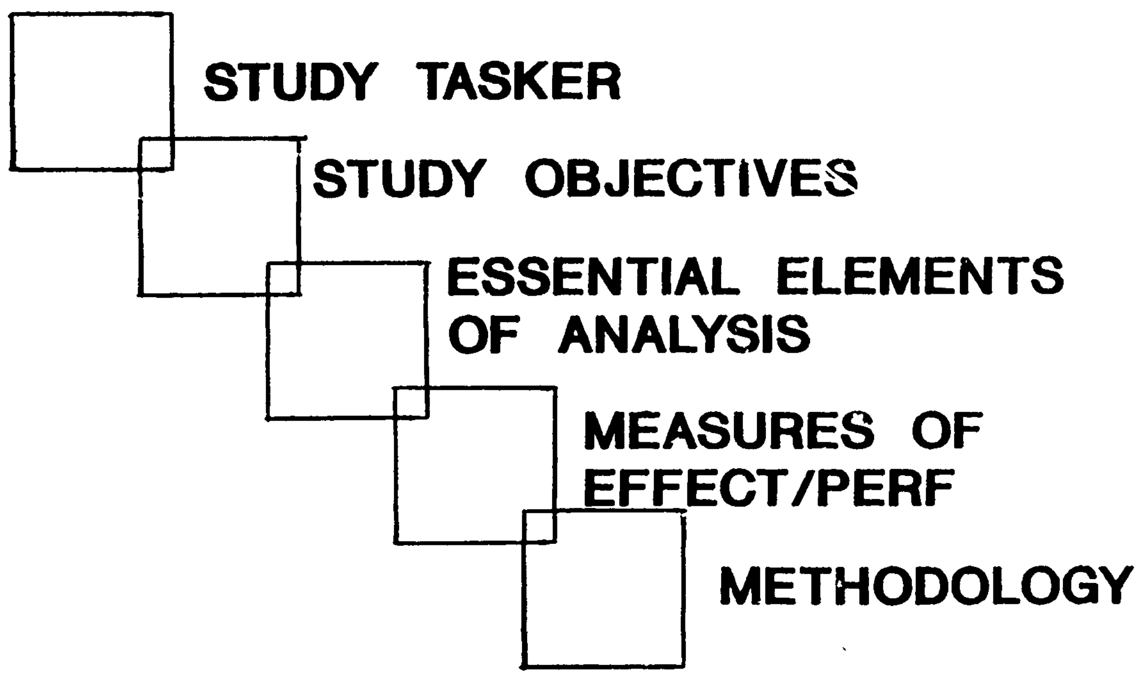

Figure I - Logic "Chain"

the best means of capturing existing expertise while structuring the planning process Novice study planners would benefit from the availability of tutorials and guidance to lead them through the logic necessary to create a sound study plan. Use of an expert system shell allowed rapid prototyping and updating of the developing system. The ease of programming was crucial in allowing incorporation of new knowledge as it became available from a variety of experts. Also, changes in any given element may cause a need for change in related elements. This type of relationship between elements is easily portrayed using AI techniques. The creation of a draft study plan in ASCII format gives the user a document which can be modified using a standard PC word processing software. The use of PC's was critical to meeting the sponsor's requirement for exportability throughout TRADOC. The C-based expert system shell will allow "bridging" into enhancement software such as graphics and critical path packages.

Methodology. Shown in **Figure II** is the SPAR milestone chart which includes completed and planned knowledge engineering sessions with various TRAC elements.

Phase I. Completed. A generic abbreviated analysis tool was developed with TRAC-Lee and LOGC local expertise. This initial prototype served as a basis for further expansion. Development during this phase focused on materiel studies.

Phase II. Expansion beyond materiel studies. Knowledge engineering sessions were conducted with subject matter experts in the areas of training, close combat, aviation, and fire support studies. Development sessions were held with TRAC-Lee, LOGC, TRAC-FLVN, HQ TRAC, TRAC-RPD and TRAC-WSMR. User-level input and valuable feedback was obtained from the Aviation Logistics School, Ft. Eustis, VA. Personnel changes within LOGC, however, necessitated slippage of further expansion into FY-90.

Phase III. Full scale development utilizing contractor resources. SPAR development will continue with growth into all study areas, expansion from AA's to COEA's, and addition of adjunct analyses such as logistics and personnel impact. Enhancements to base system will include tutorials covering such areas as MOE's versus Measures of Performance, cross-checking of EEA's to MOE's, study scheduling, and definitions. Guidance will be incorporated on conducting a front end analysis, data and model verification and validation, contract performance work statements and other areas pertinent to the conduct of a study.

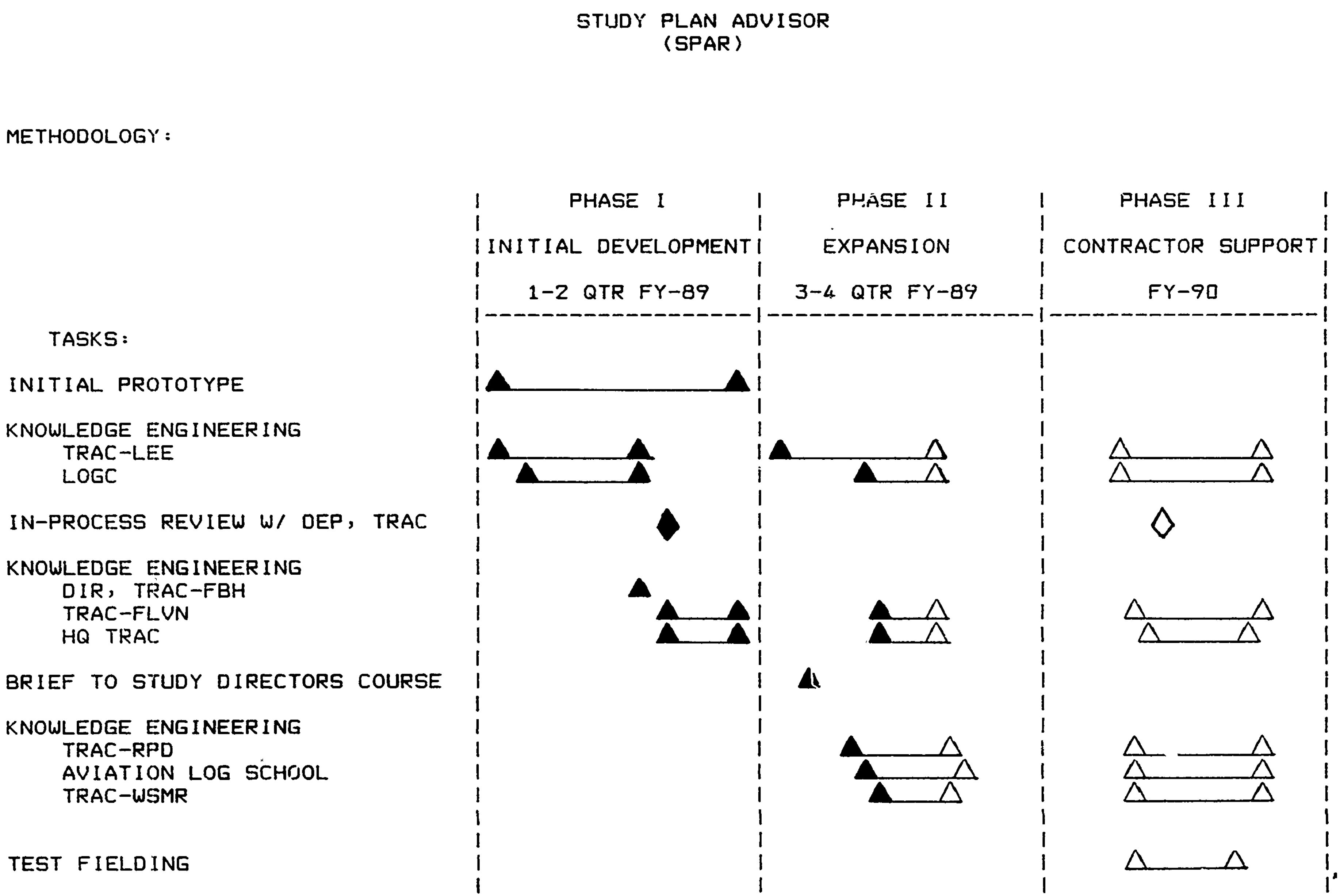

Figure II - Milestone Chart

Knowledge engineering sessions will be conducted throughout TRAC in conjunction with test fielding.

Summary. SPAR will assist planners in "pulling it all together." Novice planners will be guided through the process with help available when and where needed. A draft study plan will be built in ASCII file format for further expansion and tailoring. A rough milestone chart will help the planner recognize time requirements for scheduling of required tasks. The PC AI environment facilitates the gathering and assimilation of domain knowledge. Knowledge engineering sessions can be quickly incorporated into the system. Distribution throughout TRADOC can be accomplished utilizing the large existing PC base.

KIBOWI, a training wargame for the Royal Netherlands Army

Contribution to the Twenty-Eighth US Army Operations Research Symposium, 11-12 October 1989

by

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1. INTRODUCTION

Research at the Physics and Electronics Laboratory (FEL) of the Netherlands organization for applied scientific research (TNO) is focussed on sensor technology, system development, information technology and operations research.
Within the Operations Research division combat simulations and wargames are used since 1963.
The use of wargaming for other purposes than research was first introduced by the wargame SOLTAU in 1981.
The wargame SOLTAU was developed for the Army Staff College to support tactics training at brigade and division level in the higher military education program.
Two basic requirements were fullfilled in SOLTAU: ease of use and concentration on intelligence (S2) and operations (S3).
SOLTAU uses a 100 x 70 km digitzed terrain subdivided in 1 km square grid, superposed are natural and artificial obstacles (e.g. rivers and minefields) and unit descriptions are based on weighted unit values (see also ref. [1])
Starting in 1983 more and more use was made of the SOLTAU wargame for research (doctrine development, weapon procurement) and command post exercises.
In 1985 and 1986 a number of command post exercises at battalion, brigade and division player level were succesfully supported with the SOLTAU wargame on a set of micro-VAX computers.
In comparison to the traditional Command Post Exercises the following benefits of the computer assistance were established (see also ref. [1]):

1. open ended exercises, exercise scripts and timelines only globally restrict free play;
2. battle actions are represented in a detailed, realistic and consistent way;
3. players and lower control acquire considerable knowledge about organization and doctrine of the opposing party;
4. all exercise data are logged for replay and evaluation and although the computer equipment and wargame use asks for some consideration;

5. computer assistance is possible from battalion up to division player level;
6. exercise locations can be chosen freely, normal military communication systems can be used and player staffs can operate from their command post in the field;
7. computer hardware is transportable to any indoor location and the computer assistance can be fully hidden from player level.

Seeing the benefits, and knowing the SOLTAU deficiencies FEL-TNO was tasked in 1986 to develop a new wargame system (called KIBOWI) to better the SOLTAU wargame, i.e.

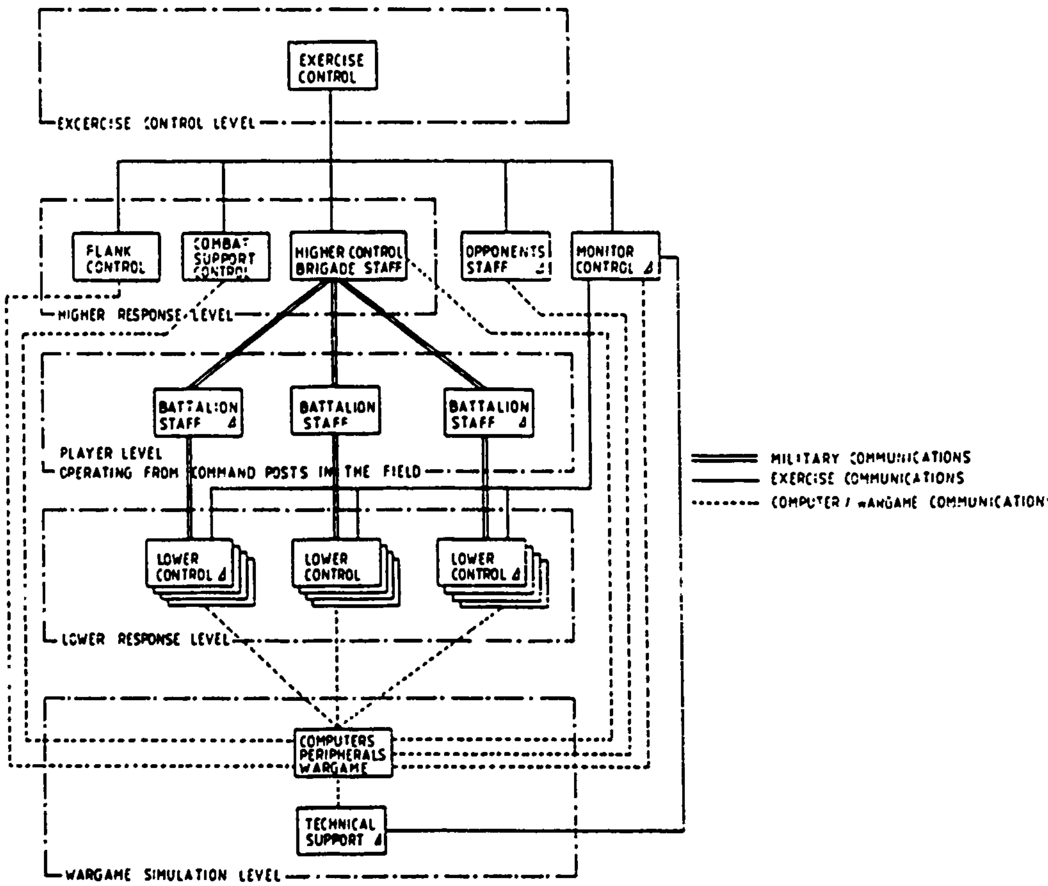
1. enhanced terrain resolution;
2. more detailed unit description;
3. more detailed evaluation of direct and indirect fire;
4. introducing the battle support functions;
5. giving more adequate lower control response facilities.

The KIBOWI project will reach the prototype state at the end of the year 1989.
In between SOLTAU is still used, especially for the brigade and division command post exercises of 1 (NL) Corps.
From 1987 onwards KIBOWI is used more and more. First in tests only, and, starting in 1988, in battalion command post exercises and the Training Command officer courses.
In chapter two the paper describes the organizational setting and expected use for KIBOWI in the Netherlands Army.
In chapter 3 the KIBOWI model description is given, chapter 4 deals with the hard and software and chapter 5 and 6 give some of our experiences during tests and our anticipation of future developments for KIBOWI.

2. <u>THE COMPUTER ASSISTED COMMAND POST EXERCISE</u>

For a good understanding of the function of a wargame system to support a command post exercise the following section will shortly summarize the organizational setting (see figure 1).
The command Post Exercise is a type of exercise meant to train a staff called player level in its command post in a simulated war environment.
In order to reach the exercise goals the exercise control unit is coordinating the exercise by direct contact with all the control participants (enemy included).
The player staffs are linked to their own operational commanders and command their own units (lower-control). Depending on the exercise set up, the player staffs can be in the field in their own tactical deployed command posts or in another location. When not operating from tactical deployed command posts, communications should be as real as possible.
Higher control commands the player staff and must perform functions such as engineer or artillery in support of the player directly into the wargame. Higher control does not control the enemy players, but does control the tactical actions of the player and as such is responsible for a large part of the exercise goal(s).
Flank control fills the information gaps left by higher control to give both enemy players and player staff(s) a complete battle picture.

The enemy players are traditionally fighting the battle according to some basic settings made prior to the exercise to make the exercise successfull.
The monitor control is introduced to sort out or redirect situations due to wargame shortcomings and control unit errors. One important task is to inform both higher and exercise control of tactical situations prior to their "discovery" by lower control, player staff(s) and higher control. This task when neglected will make exercise control impossible due to the large number of imperfect interpretations and long delay times from lower control through player staff(s) to higher control.
Lower control is a crucial function to be performed in the computer assisted CPX. Lower control has the following tasks: to order his units in the wargame, to interpret wargame messages, translate these to tactical information and then send this to his commander in the appropriate way. The purpose is to make his commander believe he is in actual battle (and not playing a game with the computer).
The technical assistance is tasked to run the wargame on a set of computer systems, to provide the control-units access to the wargame (input and output) and to assist where necessary to sort out technical or wargame problems.



<u>Figure 1</u> - Organization for computer assisted command post exercise at battalion (player) level

The basic organization for large scale exercises does not differ much from small exercises. The larger scale spreads the functions over a wider area and communications will accordingly be over longer distances. As far as computer assistance is concerned, the number of computer connections will be larger and more attention must be paid to the system reliability (back-up procedures and systems) and security regulations.
Starting this year all command posts exercises by the 1 (NL) Corps of battalion and higher livel will be computer assisted.
The wargame SOLTAU will be used for the brigade and division level till KIBOWI is capable of doing this (brigade level expected in '90, division level expected in '92).
The command post exercises last in principle one week on a 24 hours per day basis. The exercise location can be choosen freely, as the complete system is mobile.
One permanent facility has been built (see figure 2) at Stroe-barracks, capable of supporting brigade sized exercises with a maximum of four battalion player staffs together with one brigade staff to be trained.
When operating on a 24 hour basis 250 controls, of which 150 lower controls (company commanders, their seconds in command and the artillery observers) are needed.

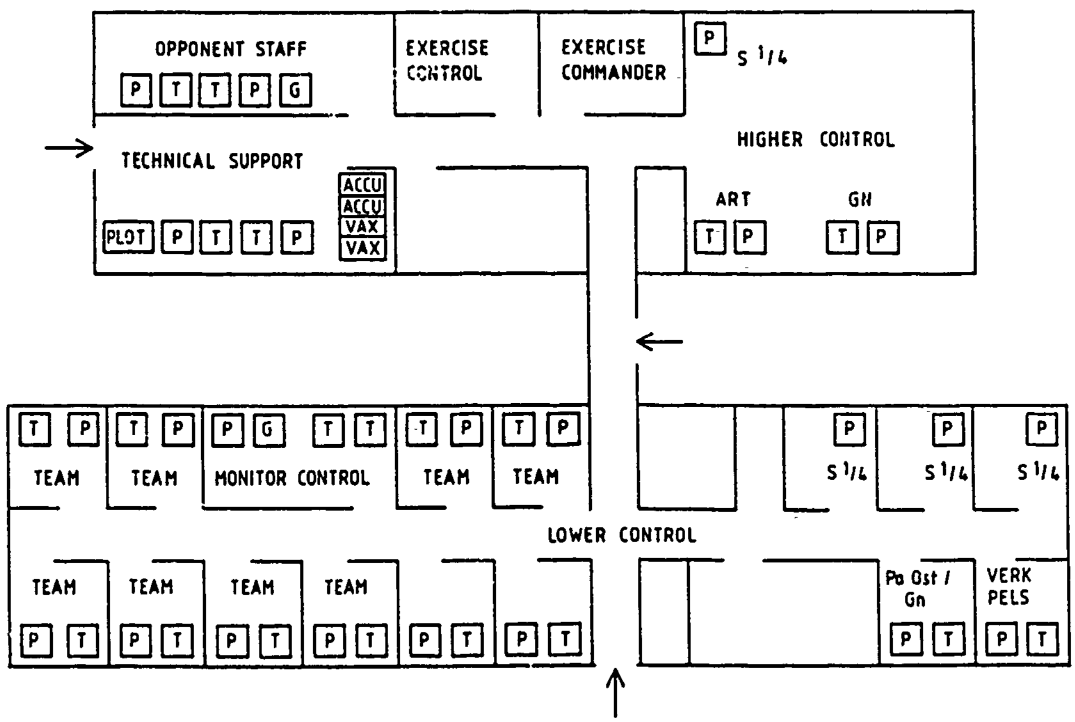


Figure 2 - Stroe barracks wargame facility

Apart from the use by the 1 (NL) Corps, KIBOWI is to support courses for company commanders, battalion staff officers and battalion commanders at the Training Command, for which a wargame facility is available at the Infantry Training Centre. For a course setting the control functions are to be combined.

The Army Staff itself is already using the KIBOWI system for study purposes (weapon procurement planning and doctrine development).
The National Sector (territorial brigades), the Army Staff College, the Royal Military Academy and the Royal Marines (UK/NL amphibious brigade) foresee the use of the KIBOWI system.

3. THE KIBOWI WARGAME MODEL

KIBOWI simulates the all-arms battle realtime and in great detail.
The basis for the simulation is the representation of the combat environment: terrain, weather, daytime, roads, bridges, water obstacles, etc. Combat units and supporting units alike are specific combinations of materiel (e.g. tanks, armoured combat vehicles), personnel (e.g. driver, commander, infantry fighting man) and stocks (ammunition, fuel). KIBOWI handles the interactions between units (sighting, fire exchange), between units and terrain (mobility) and between units and other objects within the terrain (blowing a bridge).
KIBOWI is similar to most existing models, new is the terrain and combat environment description, the simplicity and power of the detection model, the calibration factors, the priority rules for direct fire and the monitor control order set.

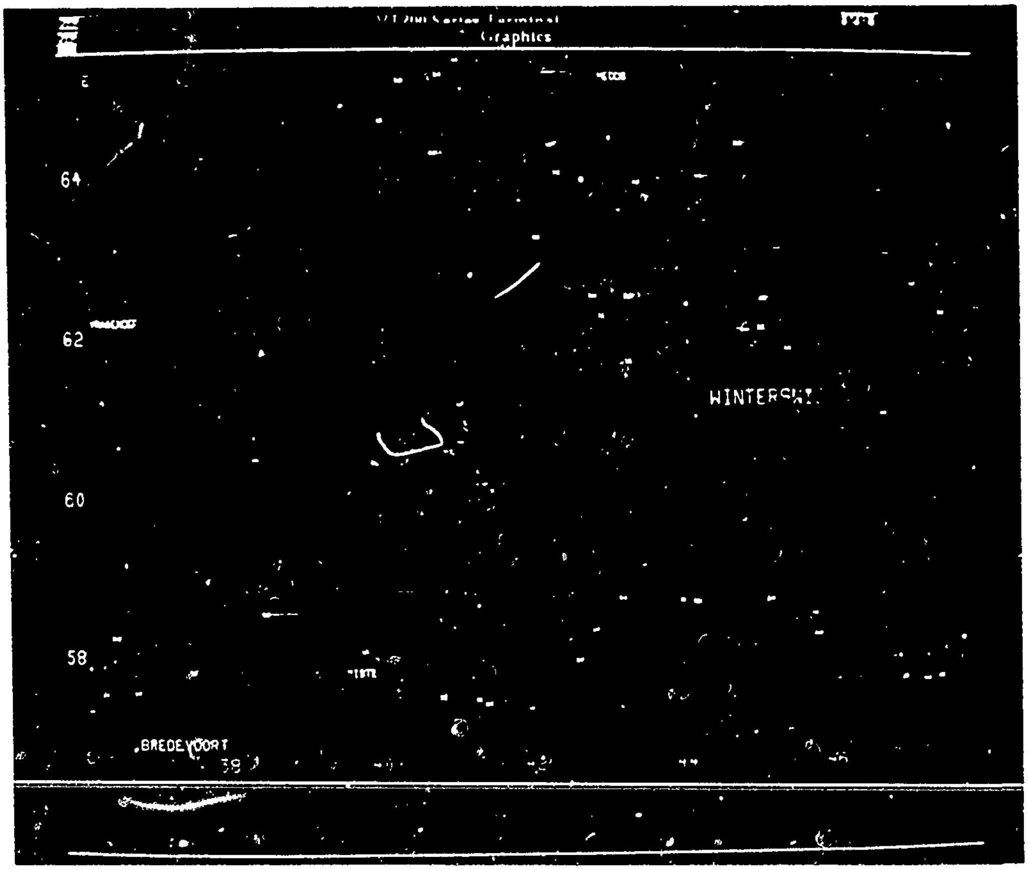


Figure 3 - Combat Environment (photograph from color graphics screen)

3.1 Combat environment

Terrain is represented by a raster of 100 x 100 meters square grids, containing terrain feature, height of terrain feature, terrain elevation (to determine line of sight) and cross country movement category (to determine speed of movement).
Superimposed on this raster are linear objects (e.g. rivers, slopes and minefields) and point objects (e.g. bridges), determining movement constraints and opportunities.
Currently three, each covering an operating area of approximately 60 x 40 km, terrain databases are available in West-Germany and the Netherlands. Only a part of the data contained in the database relies on Digital Land Mass System formatted data (terrain elevation, terrain feature category and height). The additional data was collected by the 1 (NL) Corps.

Dynamic features of the combat environment include the weather (influencing the cross country movement and the detection ranges), the daytime, smoke screens and contaminated areas. The last two features are not yet implemented.

3.2 Unit representation

Units (usually at platoon or company level) are subdivided into 8 main categories and 37 subcategories ranging from infantry to engineer units. Unit combinations can be referenced through a hierachy. A single unit will consist of vehicles (armed with weapon systems, ammunition, fuel and crew and with supporting sighting systems) personnel and stocks. Currently a database is used comprising 89 different vehicle types (ranging from tanks Leopard II, T-80 to single jeeps). With this database all current fielded NATO and WP force structures can be modelled.
Fatigue, morale and training level are affecting combat. In KIBOWI the data fields are already set to incorporate these aspects, current complexity of the game precludes their present use.

3.3 Detection

During every evaluation time-step calculations are made to determine if units really "see each other". After checking for line of sight (based on the 100 x 100 meters grid terrain description), a factor ruled detection function is used to decide if a detection takes place. The factors represent the influence of: is the enemy unit detected in previous timeframe, distance between observing and enemy unit, weather, enemy unit status, enemy unit environment (concealment, camouflage), daytime, observing unit status and means of detection.
The factors are multiplied with two preset standard values and determine the minimum detection distance (dmin) and the maximum detection distance (dmax).

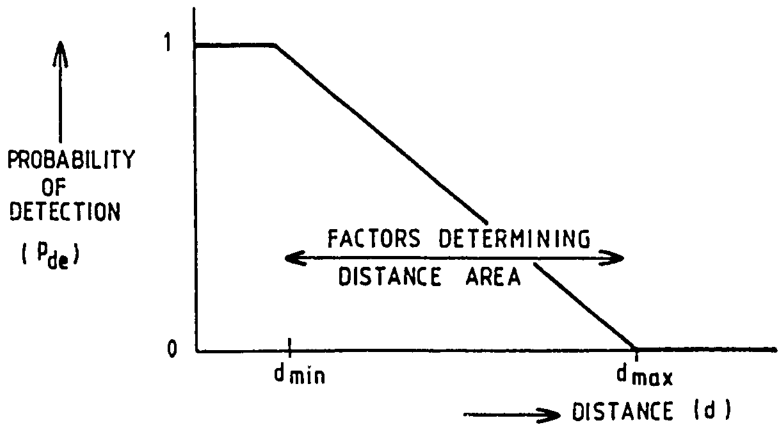


Figure 4 - Detection probability function

E.g. in clear weather dmin could be 500 meters, dmax 4500 meters, meaning assured detection for all distances below 500 meters, no detection possible above 4500 meters.
Between 500 and 4500 a random draw using the detection probability function shown in figure 4 will decide for detection to occur.

3.4 Direct fire

After detection has taken place, and having the unit ready and capable (ammunition availability) of firing, a sequence of calculations is made to:

1. Determine which unit (within sight) and which vehicle type to attack using priority rules from the database or at the choice of the unit itself by deliberate aiming.
   The priority rules allow for alternating the chosen target types by giving correlated weighting values to the target types in the priority list (the number of targets is multiplied by its weighting factor so as to determine target priority in the current fire exchange).
2. Determine the number of rounds using the weapon system database and the current dynamic data of the firing unit (status, etc.).
3. Determine the number of kills made using the dynamic data of both enemy unit and firing unit.

In the second and third calculation the weapon system data are used together with so called calibration factors. The callibration factors are set at the discretion of the army, simulating the battle stress inefficiency of early firing and having a large number of misses, and alternating battle tempos (short engagement period followed by a readjustment, recuperation period).

3.5 Indirect fire

Indirect fire is possible by artillery, mortar and rocket systems. Through the weaponsystem database, the calibre, the ammunition round type and the firing sequence times are known for the indirect fire unit. Depending on the unit status, indirect fire can be ordered by an indirect fire lower control giving ammunition type, number of rounds and target location.

KIBOWI then:

1. calculates the time (deterministic) and place (stochastic) of impact,
2. sorts out units in the rectangular damage area, and
3. uses vulnerability data from the database to determine losses (stochastic) for weapons, ammunition and personnel.

The size of the rectangular damage area depends on the calibre and the firing unit level (e.g. platoon, battery, or battalion fire).

3.6 Movement

Every time step the movement vectors of the units are determined, adjusted for cross country movement, road movement and unit status.
Vectors intersecting obstacles are treated seperately, checking for instance (for a water-obstacle) whether a bridge is available within 100 meters of the intersection of the movement vector and the water-obstacle. If no such bridge is available it is checked whether the unit could cross it independently (taking time to prepare for a river crossing operation).
For a minefield checks are made if lanes are available, and if not whether the units could breach it.
All linear and point terrain obstacles are referenced through a net structure (1 x 1 km) giving the movement algorithm only a limited number of obstacles to consider.

3.7 Logistics

Supply and resupply of ammunition and fuel are modelled by having supplies of ammunition and fuel ordered and moved through the area by units (either logistic units or manoeuver units). These units are checked for vehicle loading capacities, loading facilities and loading times.
Ammunition and fuel consumption is controlled by the direct fire, indirect fire, air defence,air support and movement processes.
Resupply or recovery of weapon systems and troops can be ordered from outside the game by monitor control.

3.8 Engineer operations

In KIBOWI a number of engineer operations is modelled: making entrenchements for platoon fire positions, bridge construction, and bridge demolition, minefield laying, minefield breaching, making passage ways through obstacles, making road craterings, tankditches, barbed wire obstacles,and wood hackings.

3.9 Helicopter combat

Helicopters are treated as all other units in the game, except for movement.
For movement three modes are available: flying under terrain cover (low speed), contour flying (medium speed) and transit flight (high speed).
Depending on flying altitude the line of sight differs from the ground units.
Helicopters using terrain cover are given first detection benifit over enemy units, loosing this benefit if they open fire (at some other unit).

3.10 Air support and Air defence

Air support from fixed wing is modelled by having single aircraft crossing the air above the operating area, release their weapons and backtrack to their staying point outside the arena. Airbase operations are not modelled.
The defence against the air support is possible by the air defence units using their airdefence weapon systems and the units within the vicinity of the release point (having line of sight with the aircraft), using their direct fire weapon systems.

4. THE KIBOWI WARGAME SYSTEM

4.1 Hardware

The KIBOWI system runs on a Local Area VAX-network (using micro VAX systems) or a VAX cluster and can be (and is) operated from any indoor location.
The prototype will consist of at least 2 micro VAX computers, 7 VAX2000 graphics systems, 15 VT320 terminals and 15 printers, one plotter, one colour printer and possibly one video projector.
In the envisaged product version for a full brigade exercise up to 20 VAX2000 systems would be needed.

4.2 Software

KIBOWI has been implemented in ADA. Two supporting packages were developed to seperate the wargame software from the VAX/VMS environment: ATD (Advanced Terminal Driver) and GRAPHICS (GKS graphics binding with ADA).
The KIBOWI software is subdivided into a number of programs running simultaneously on more than one CPU. The major programs are:

1. Operator
   To control all KIBOWI processes, readjusting for hardware failures, making backups, restarts, etc.
2. Database manager
   To create exercise databases and to facilitate and control all database access, either by the evaluator, or one of the server processes.

3. Server
To connect a set of interfaces to one VAX-CPU in the network.
4. Evaluator
To evaluate all combat processes and to store situation updates in the dynamic database.
5. User interface
To give access to combat information in a controlled way (only those information which is known to the lower control subordinate units), transferring orders from lower control to evaluator.

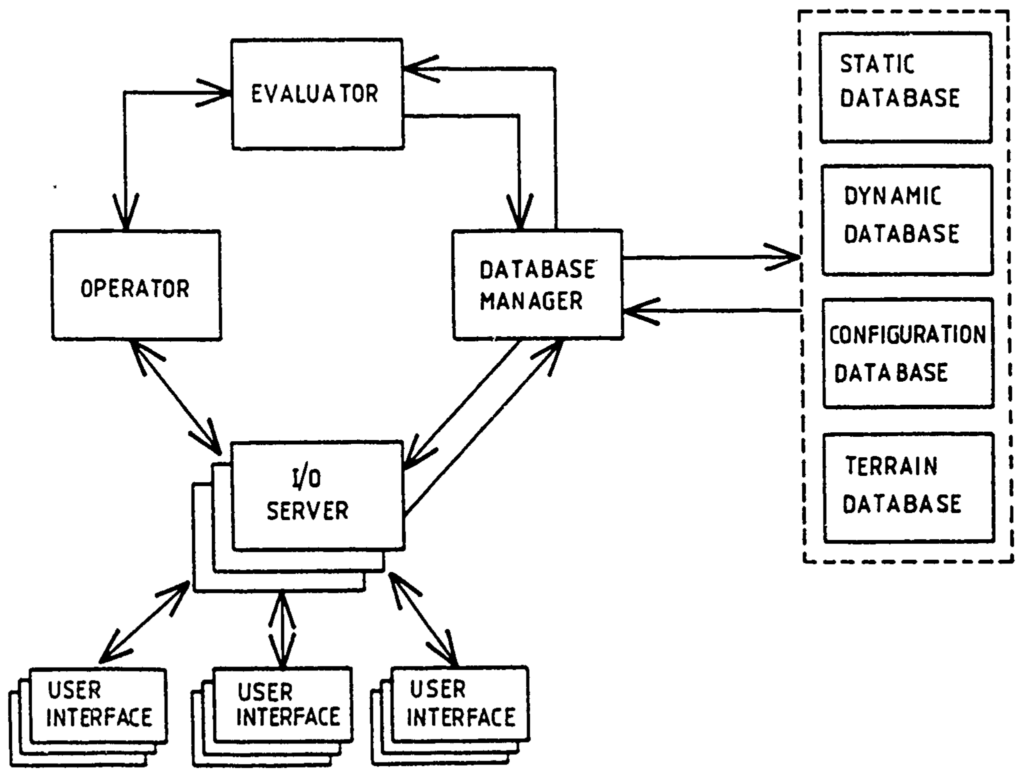


Figure 5 - KIBOWI software

4.3 User interface

The lower control interface of KIBOWI is based on a menu driven orderinput and a color graphics output, optionally available is printer output.
The graphics stations provide real time information about subordinate units as an overlay on the KIBOWI combat environment display, showing movement, detection, direct fire and indirect fire, from the subordinate units point of view. The input terminals are menu driven and provide help functions for desired actions.
As examples of the available functions:
Lower control can inspect platoon positions by making line of sight pictures on the graphics screens during the game.

Units can be ordered move to a fire position, open fire and retreat in one sequence called the fire raid. The ability to order sequences of single operations enables for lower control to actively fight the battle at company level.
For monitor control and exercise direction, graphics stations are available, combined with color printing and plot facilities.

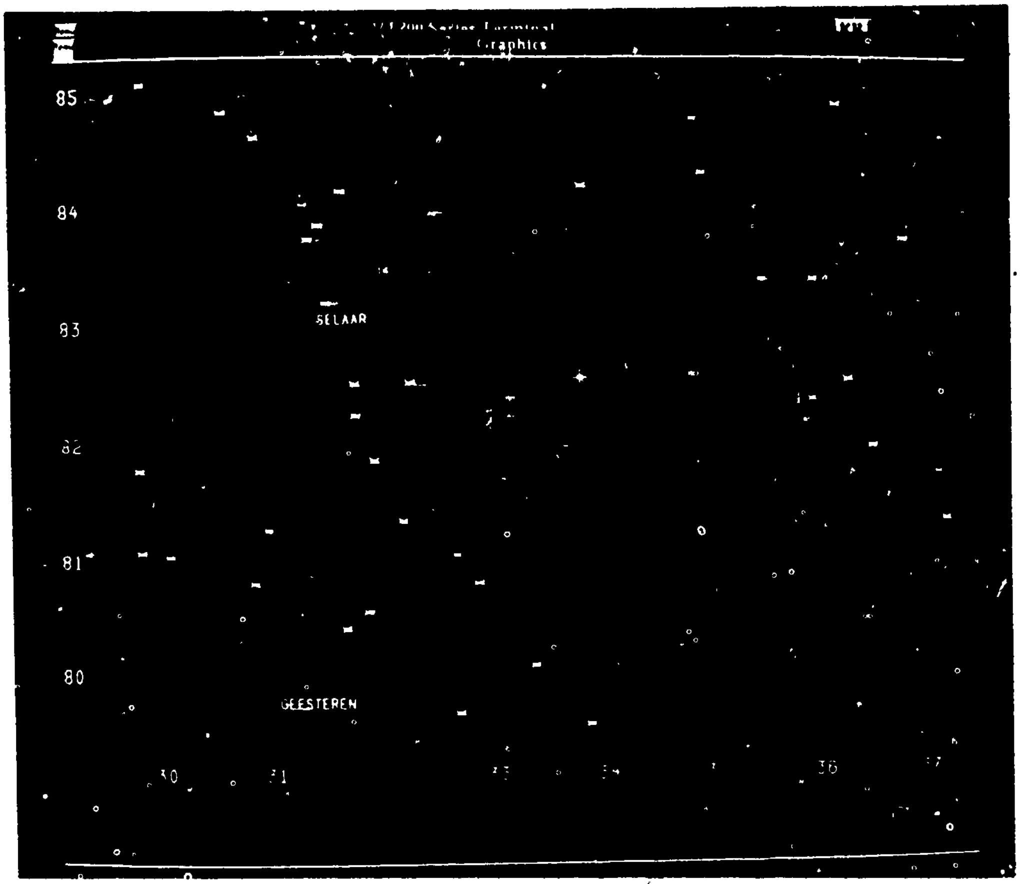


Figure 6 - Line of sight diagram (photograph from color graphics screen)

Figure 7 -Lower control hardware

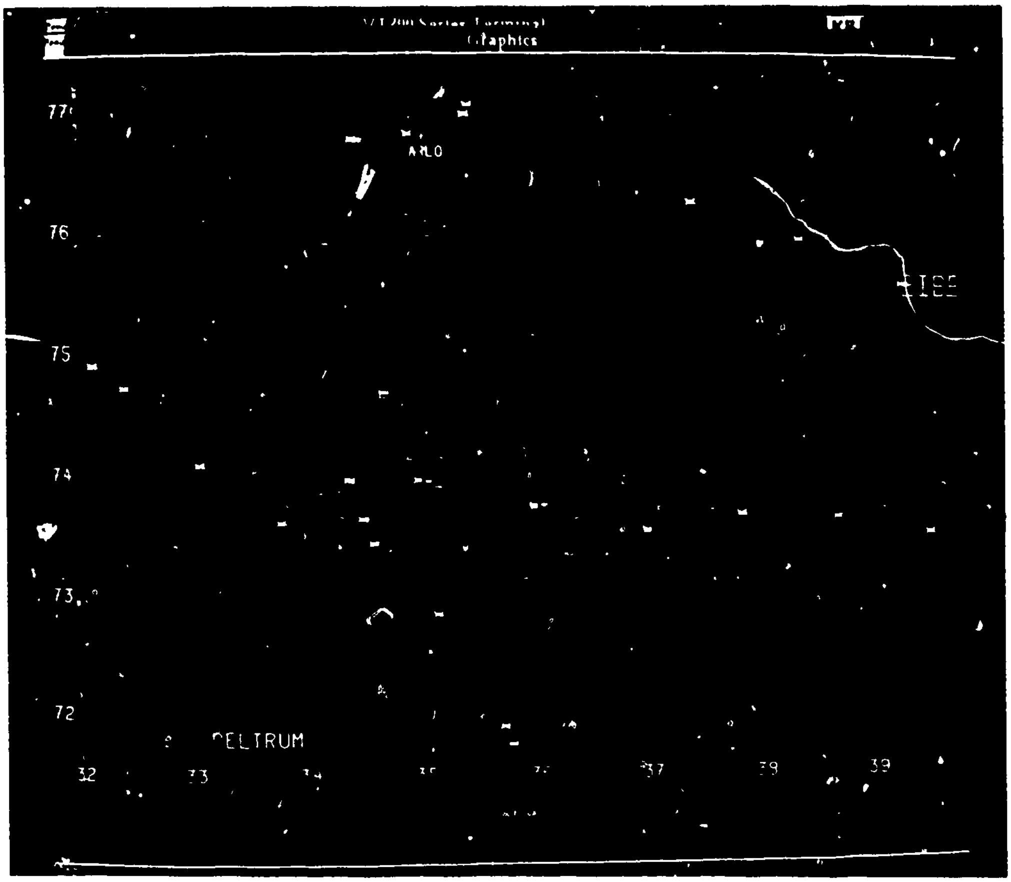


Figure 8 - Combat situation display, photograph from color graphics screen

5. CURRENT TESTS AND USE OF THE KIBOWI PROTOTYPE

Following the rapid development of a laboratory test version of the KIBOWI system, extensive user tests were conducted.
The first tests (1987) were executed at the Physics and Electronics Laboratory using groups of military experts from the different branches. The tests in 1988 and 1989 were conducted both at the training command (course situation) and with the 1 (NL) Corps (Battalion staff command post excersises). During the tests a number of deficiencies were corrected. The CPU performance of the current micro-VAX'es increasingly proved to be a problem for running real-time.
For the end of this year a brigade command post exercise is scheduled, using a new VAX-system to overcome this performance problem.
The tests also made it clear that KIBOWI owing to its high level of detail is difficult to handle; hence research is spent to further simplify control operations (lower control, monitor control and enemy play).
KIBOWI (as other wargames do) when used for training, stimulates discussions about the crucial factors dictating war and combat operations within it.

6. FUTURE DEVELOPMENTS

After the final test of the prototype at brigade level november this year, the prototype will be delivered to the 1 (NL) Corps and the Training Command to be used during 1990 and 1991 CPX's and courses.
A delivery of two complete KIBOWI systems for the Netherlands Army is scheduled in 1992.
At the Physics and Electronics Laboratory further developments will be concentrated on making KIBOWI capable of supporting division and army corps exercises, and making better evaluation tools.

7. REFERENCES

[1] Is it possible to use wargaming techniques in training and adepting them to the tactics of 1 (NL) Corps?
Contribution to the AC/243 (Panel 7) symposium on wargaming 9-11 February 1987, by Ir. W.C. Borawitz and LtCol. L.A.C.M. Coopmans.

#218

TITLE: Tactical Helmet-Mounted Display and Pocket Computer System

AUTHOR: James Schoening

ORGANIZATION: US Army CECOM
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COMMERCIAL: (202) 532-0118

ABSTRACT:

SYSTEM DESCRIPTION

The Tactical Helmet-Mounted Display and Pocket Computer System is a complete computer system for the soldier of the future. It will be lightweight, compact, hands-free, fully portable, multi-purpose, and will be comprised of the following:

1. Helmet-mounted display for visual output.
2. Miniature solid state computer.
3. Short distance radio for voice/data communications.
4. Handheld joystick and/or voice recognition for user input.

PURPOSE OF SYSTEM CONCEPT PAPER

The purpose of this paper is to explore various tactical military applications for helmet-mounted displays and miniature portable computers and to assess the various components and technologies which would make up such a system. Comments on any or all parts of this paper are welcome and should be referred to James Schoening (201) 532-0118 or AUTOVON 995-0118. Mailing address: US Army CECOM, Advanced Systems Concepts Office, AMSEL-RD-ASCO-SC, Ft. Monmouth, NJ 07703.

#177
TITLE: AWACS Support of Corps Operations

AUTHOR: Carl Driskell

ORGANIZATION: Headquarters, US Army V Corps
APO NY 09007

ABSTRACT:

The capability of the NATO Airborne and Control Systems (AWACS) to support Corps operations is analyzed. Specific areas of AWACS support include assistance to helicopter deep operations, early warning of threat helicopter attacks, and targeting of enemy refueling and staging areas. AWACS technical capabilities are presented based on data collected during joint NATO - V Corps missions conducted in the Federal Republic of Germany.

Paper is Classified
Requests or questions should be
referred to originating agency

THE CINC'S FORCE ANALYSIS SYSTEM -

A Concept Development Using Rapid Prototyping Techniques

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Operations Research and Systems Analysis Cell
Heidelberg, West Germany

PURPOSE AND INTRODUCTION

The purpose of this paper is to describe the methods used to develop the concept for "The CINC's Force Analysis System" (FAST). The importance of the method is not in complex mathematical theory or statistical manipulations. In fact, no higher level mathematics will be discussed in this paper. However, the method which developed in the process of this systems analysis and concept development is noteworthy due to its success in capturing the requirements of the user and translating those requirements to the decision maker and the developing contractors. Another benefit of the approach is its focus on the ergonomic considerations in the concept design. Both of the positive aspects of this approach are important to Operations Research and Systems Analysts, who are not truly successful unless their products are used. Examples from the concept resulting from this analysis are provided. A glossary of terms is provided at the end of the paper.

BACKGROUND

The Commander in Chief of US Army Europe (CINCUSAREUR) expressed to the HQ USAREUR ORSA Cell his requirements for the system. The stated requirement was (in part) to view the constitution of the USAREUR forces (1) as planned for arrival from CONUS in the event of war, (2) as actually arriving in the event of war (or in an exercise such as REFORGER), and (3) considering the level of operationally capability. CINCUSAREUR further expressed the requirement to conduct "what-if" analysis on the planned flow of units in order to analyze contingencies and to "maximize" the force. CINCUSAREUR tasked the ORSA Cell to develop the <u>concept</u> and systems <u>requirements</u> for the "The CINC's Force Analysis System" (FAST). The three system requirements stated above will be the focus of this paper and are more specifically described below.

(1) Analyze the personnel, organizations, cargo, and Battlefield Operating Systems within the Time Phased Force Deployment Data (TPFDD) and determine the effects of TPFDD changes on the balance of the USAREUR force.

(2) Analyze the constitution of the USAREUR force during execution of the TPFDD (in the event of war or in

exercises) by tracking arrivals in theater and the effects of those arrivals on the balance of the USAREUR force. (3)

Analyze the effects of the true combat capabilities of individual units in USAREUR on the balance and capabilities of the USAREUR force as a whole.

INITIAL ANALYSIS OF THE PROBLEM

An initial analysis of the problem involved interviews. with the action officers within HQ USAREUR DCSOPS and DCSLOG in order to determine the staff level system requirements to support FAST. The initial analysis also required an assessment of the existing data sources, hardware systems, and methods of force analysis.

Figure 1.0 displays the schematic of the laydown of the network of data and systems required to support the CINC's FAST System. Primary systems in existence required to support FAST are WWMCCS and UTACCS.

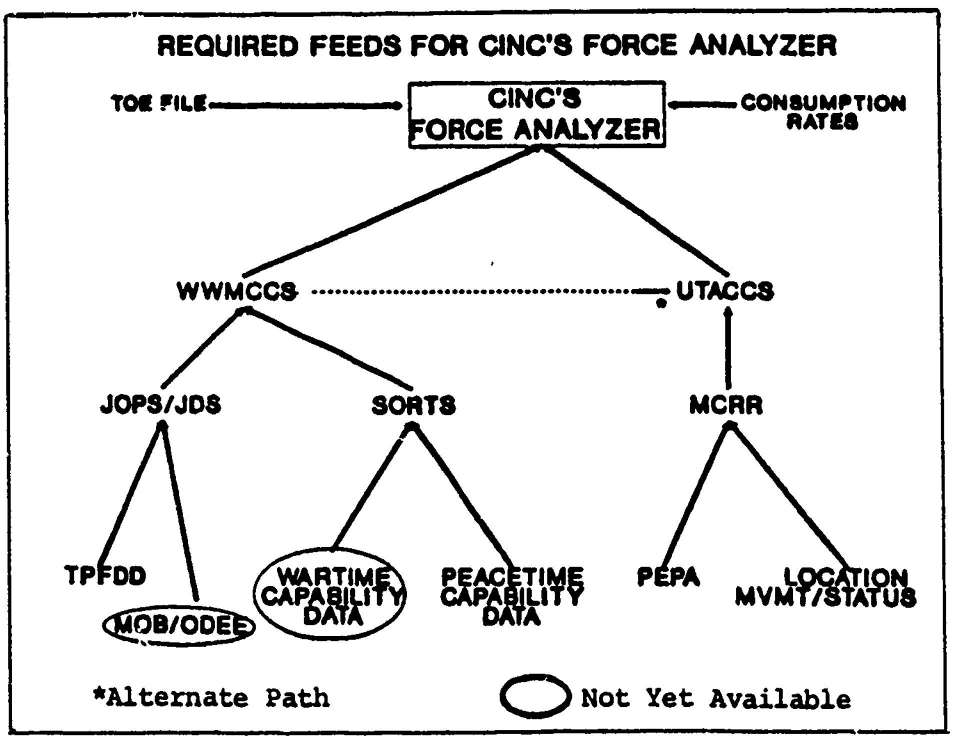

Figure 1. Required Feeds for CINC's Force Analyzer

Through the systems shown in figure 1, it was determined that most of the required data was available. (The exceptions were mobility/operational deployment data and the wartime equivalent to SORTS). However, the data was not pulled together in one system and the data required significant manipulations to satisfy the requirements for FAST. Therefore, the problem initially appeared to be one of documenting the interfaces and manipulations required.

AN INITIAL SOLUTION - UNSATISFACTORY

In order to document the system requirements, a requirements document was written and presented to HQ USAREUR ODCSOPS and ODCSLOG. Then, two more requirements documents were prepared and presented to the staff. In each document, the three required system functions (as described in the BACKGROUND paragraph, above) were broken into sub-functions which were described according to purpose, data required, and manipulations required. However, in no case did the anaiysts feel that any real communication was taking place between the ORSA analyst and the operators (ODCSOPS and ODCSLOG) via the technical requirements document. How could we be sure we were capturing the true requirements? And how could we be sure we were fully communicating those requirements to potential developers? Furthermore, the task of presenting the concept to CINCUSAREUR in such a way as to support a development decision was daunting.

THE SOLUTION

It started first with some rough drawings of requirements versus capabilities curves. When presented to the operators, feedback was provided on specifics as to how the presentation supported requirements, as well as how the presentation could be made better. The operators became extremely interested and involved with this process. A true communication of requirements was taking place. Soon, this approach was expanded to each function and each sub-function within the requirements document. Sketches turned into complex graphics which included details such as menus and "time toggles" which allowed the user to choose the category and timeframe for viewing.

The Harvard Graphics slide show which contained the graphics was transported to a major NATO Command Post Exercise (WINTEX/CIMEX) when the ORSA Cell (on mission essential status) accompanied USAREUR to the field. At request, COMCENTAG, CINCUSAREUR, CofS USAREUR, USAREUR DCSOPS, and numerous staff officers were presented with the FAST concept in graphics. In this operational environment, using the graphically illustrated concept, an invaluable communication process occurred between the concept developers and the operators. COMCENTAG and CINCUSAREUR, among others, were facing operational problems which could be immediately addressed and the methods for solving the problems could be immediately incorporated into the system concept. The concept evolved specifically around the real operational problems.

Through the very interactive process which developed between the operators, the decision maker, and the analysts, a complete and detailed concept was developed. To document the resulting concept, a Functional Description (FD) was written around the graphics. The FD included descriptions of interfaces, data requirements, and mathematical manipulations required for each sub-function or graphic display.

The graphically displayed concept was extremely successful in supporting a development decision by CINCUSAREUR, who could see precisely what product he was buying. The functional description is currently being used extensively in the development of the CINC's FAST System for USAREUR.

CONCLUSIONS

In review of the method used, we have determined that the process used is actually a form of "rapid prototyping". Rapid prototyping is currently being used by software developers to bring the user into the development process. Throughout the development of the system, users are provided successive models of the system so that input is provided based on "hands-on" use, prior to full development. As in the case described above, this facilitates the development of the system towards the precise needs of the user, even when the user doesn't know exactly what is required on the outset.

A significant benefit of this approach is the consideration to the "man-in-the-loop." Many of the existing systems evaluated during the above described analysis have extremely poor ergonomic design, leading to misuse and disuse. Computer output which presents data in an understandable format is critical in any environment, but especially in the high stress environment which would be experienced by a USAREUR staff officer in wartime.

The approach applied here reduced the risk for the development of the CINC's FAST System. Risk was reduced due to three factors:

(1) Specific requirements of the users were captured,

(2) The decision maker "saw" the product before he bought it and therefore knew whether or not the product fulfilled his requirement, and

(3) The product of a functional description complete with detailed graphics serves as a specific communication device between the users and the developers.

In closing, presentation of information in an understandable way is as critical as the retrieval of the data. Aggregation and manipulation of the data in order to make it meaningful is essential. In the words if the former DCINC USAREUR, Lieutenant General Stotser, in reference to the WINTEX/CIMEX evening brief, "I am presented with series of data from numerous different sources and am expected to sit there, absorb it, act like a computer, and spit out the answer. What I need to have presented to me is information." This system is to be used by the staff in support of the CINCUSAREUR, one objective of the system is to address the problem the wartime CINCUSAREUR discussed in the quote.

FAST EXAMPLE GRAPHICS

The following graphics represent a sampling from the FAST concept. The computer graphics use numerous color codes, as well as the design codes seen in the graphics presented here, therefore the graphics here are actually incomplete in the story that they tell.

The graphic slides consist of a title, a graphic portion, a legend, up to three notional menus, and a "time toggle". The title simply gives a general description of the contents, the legend further describes the graphics, the notional menus present a general requirement for a menu driven, user friendly system. The "time toggle" represents the capability to "toggle" across time through different time windows while watching the effect on capability.

Throughout the graphics, notional unit designations are used. All data presented here is for presentation purposes only and does not represent true data or situations. The graphics presented here, as well as within the functional description, represent the general characteristics of the output required of the CINC's FAST system and are not designed to necessarily to be copied directly during system development.

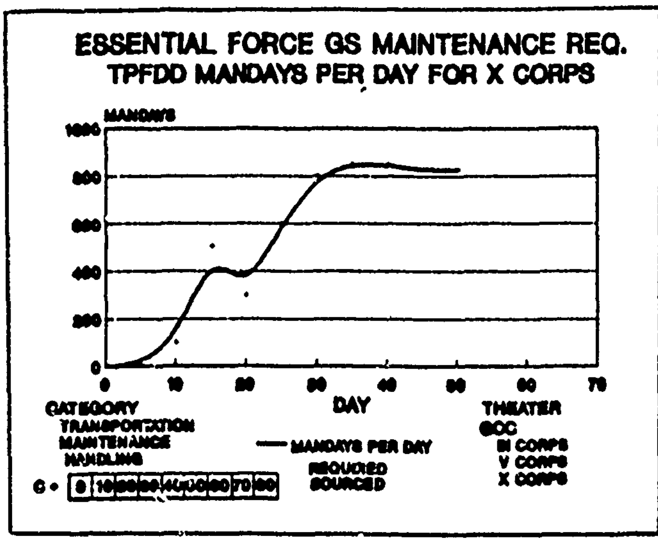

Figure 2.a

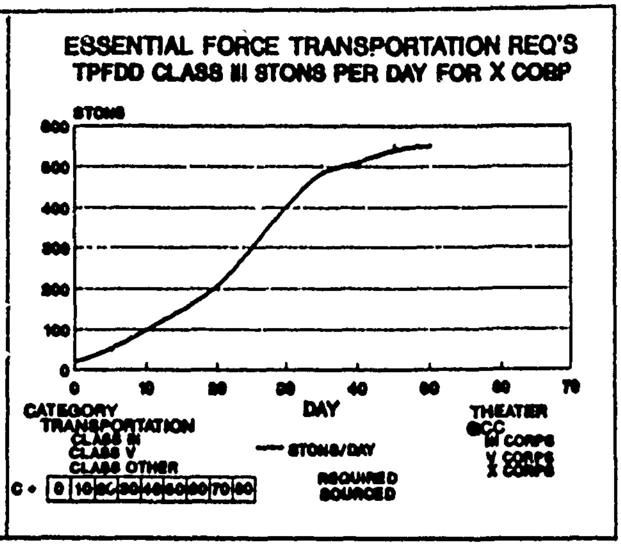

Figure 2.b

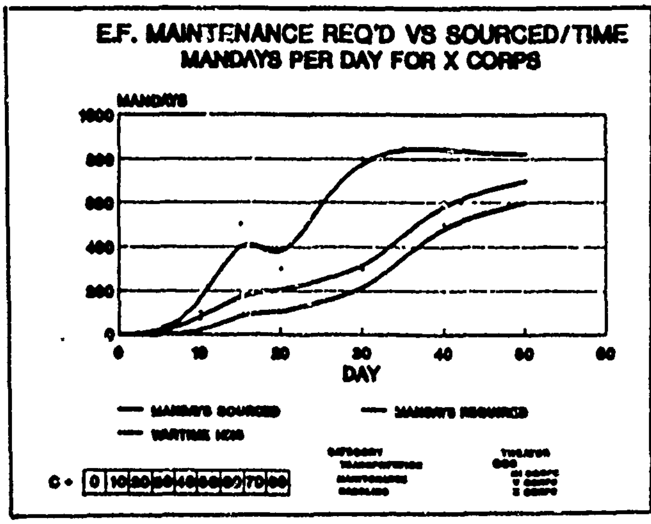

Figure 2.c

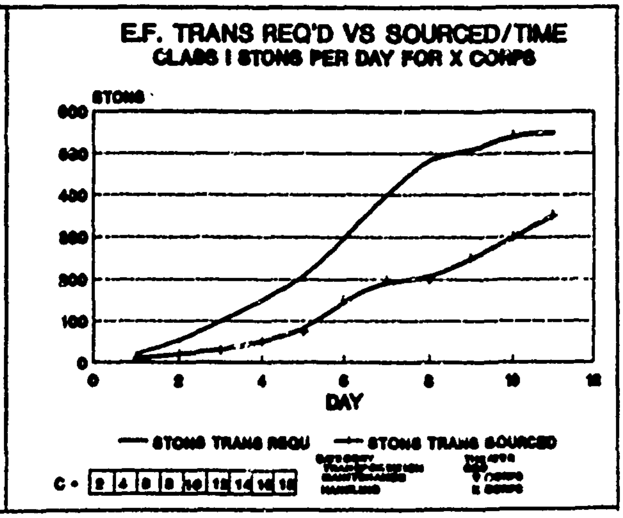

Figure 2.d

Figures 2.a. through 2.b., above, represent the capability to display resource and organization availability. Figures 2.a. and 2.b. display the resources available within the planned TPFDD, per day, within the theater or within a particular gaining command, to support the combat units. Figures 2.c. and 2.d. represent the capability to display and compare the resources within the planned TPFDD to the resources within the sourced TPFDD. Figure 2.c. also provides information concerning the Wartime Host Nation Support Capabilities.

The system must be capable of overlaying numerous descriptive lines on the same chart, or displaying multiple charts simultaneously. The user must be able to select CSS categories and subcategories, as well as a data for a particular Gaining Command Code (GCC).

The capability curve is generated by multiplying the number of units available by the capability attributed to that unit based on the unit TOE.

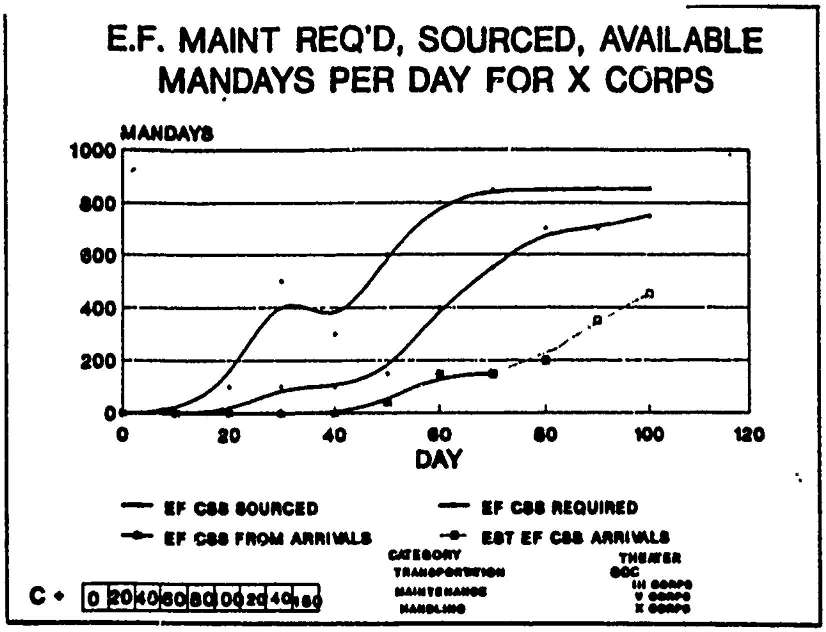

Figure 3.a

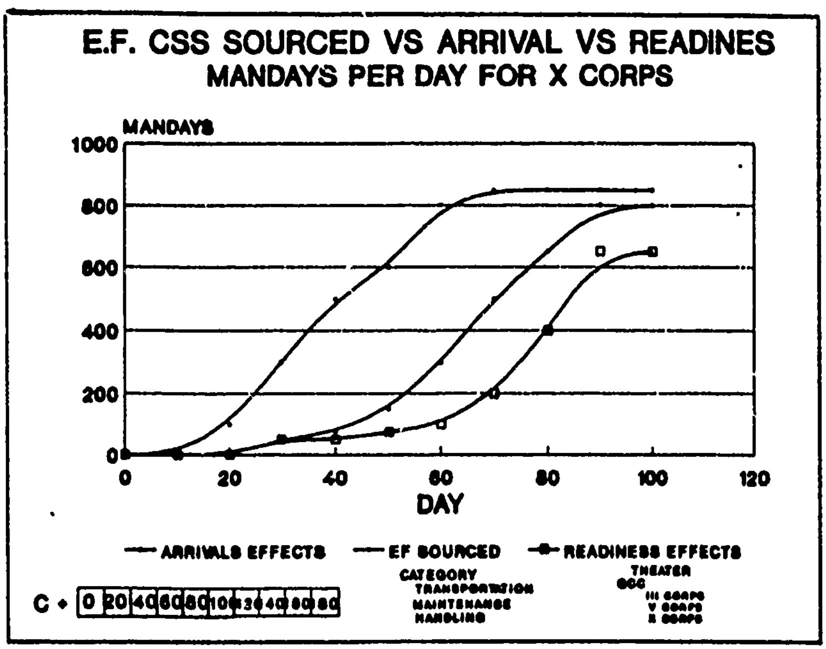

Figure 3.b

Figures 3.a. and 3.b., above, represent the system capability to display resource and organization availability and combat readiness. Figure 3.a. represents the system capability to displa" TPFDD requirements versus sourced TPFDD capabilities versus ual and projected arrivals (based on actual Force Reception and Onward Movement (FROM) data). Figure 3.b. represents the capability to display sourced TPFDD capabilities versus actual arrivals versus the combat capability of those arriving units (based on the status as of the last report date). The curves are generated in a similar fashion to those in figures 2.a. through 2.d., though the sources of the data would be different.

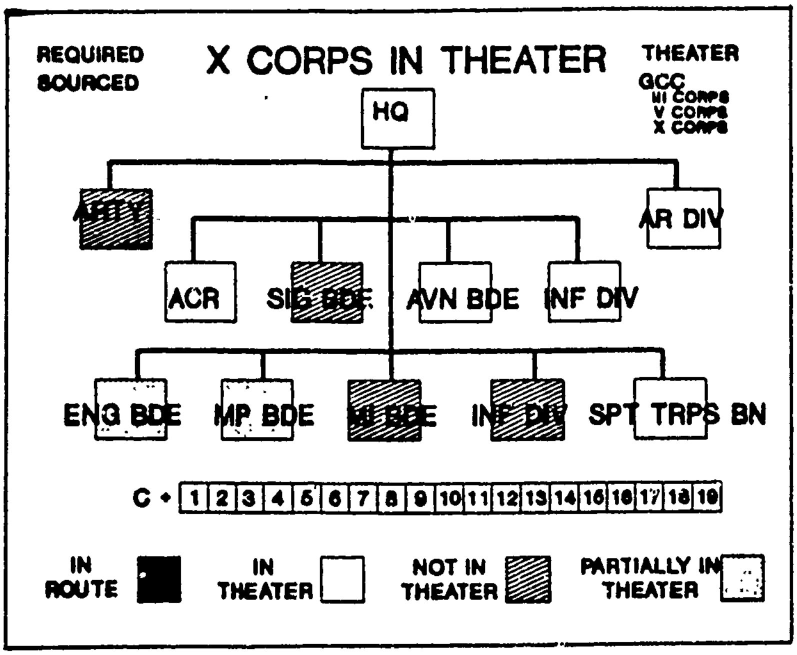

Figure 4.a.

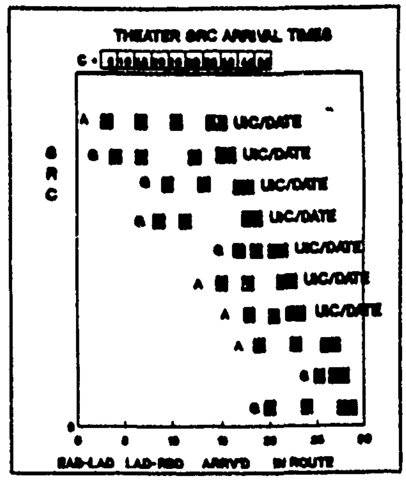

Figure 4.b

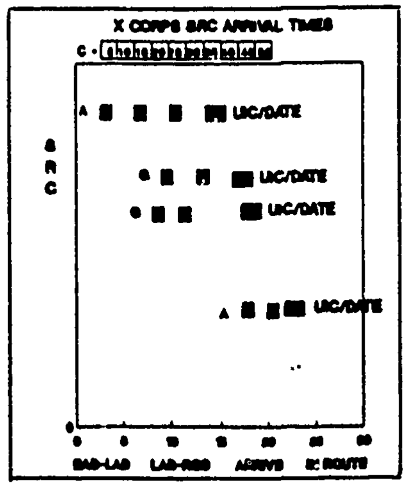

Figure 4.c

Figures 4.a., b., and c. represent the system capability to display either the status of the entire gaining command or the status of a particular type of unit. These system capabilities work well together as a unit.

Figure 4.a. represents the capability to retrieve necessary information and display an organizational chart for each gaining command code within the TPFDD or within the theater. Immediately subordinate commands should be displayed as well as the headquarters element. The status of the units, as well as the readiness of the units, should also be displayed. The user must be able to toggle across time and watch the status of the organization change. To access status of the subordinate units, the user must be able to put an icon in the box of the subordinate unit, toggle, and "open-up" the organizational chart for that subordinate unit.

Figures 4.b. and 4.c. represent the capability to display the arrival windows of each unique unit within a given type of unit. In this way, the flow of all units within a particular type is shown as they arrive in theater in pieces (otherwise known as Unit Line Numbers). Gaps within arrivals may be observed and eliminated, or units coming in may be reassigned based on requirements. This data must be retrievable by theater or by gaining command.

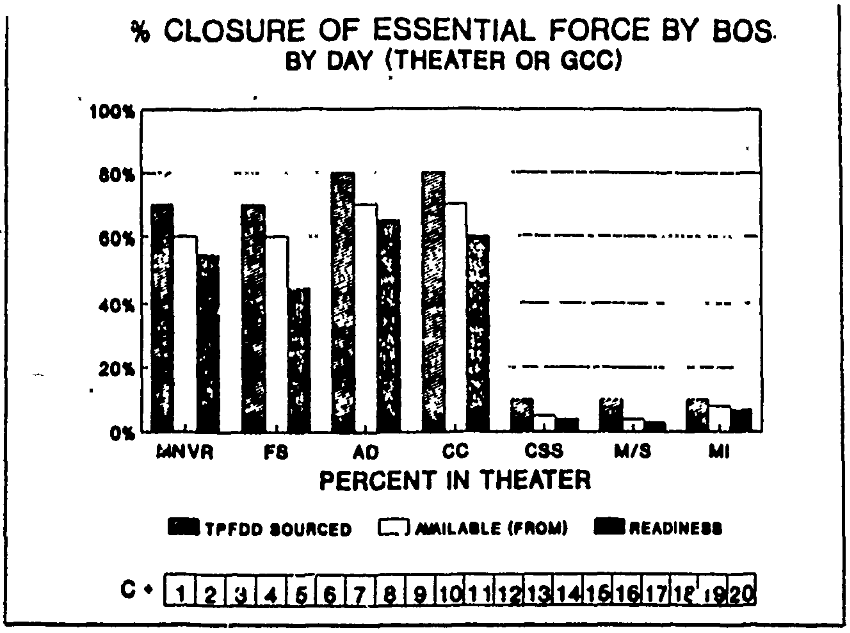

Figure 5.a

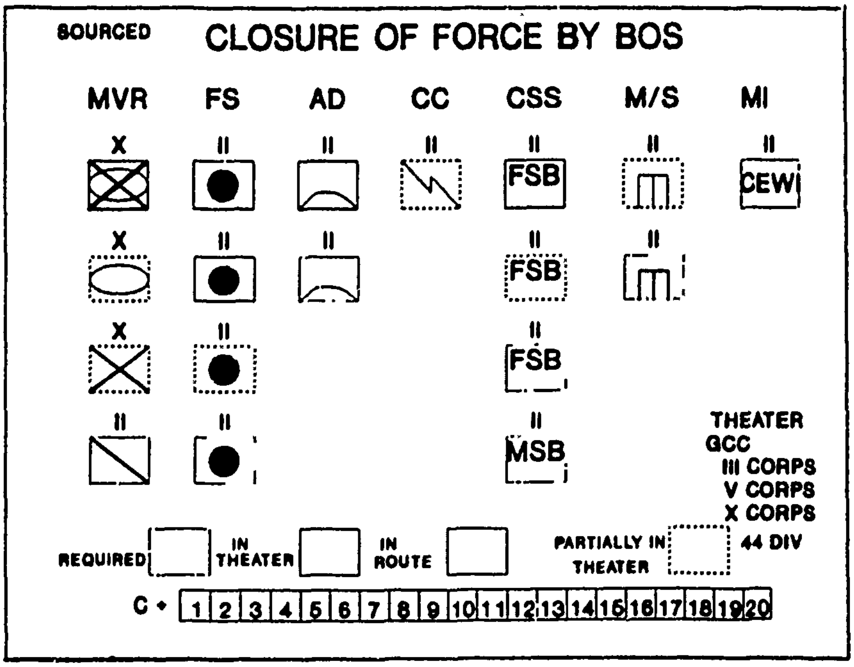

Figure 5.b

Figures 5.a. and 5.b. represent the system capability to display the 'balance of the force' according to Battlefield Operating Systems (BOS). These particular figures display the BOS status for the essential force (EF). Figure 5.a. represents the percentages of both capability and availability of units. Figure 5.a. therefore presents an overall picture of the 'balance of the force'. Figure 5.b. represents the system capability to display all units within a gaining command code according to their respective BOS. Further information is also displayed here, such as the status and capability of the unit. Figure 5.b. therefore presents a detailed picture of the 'balance of the force'.

GLOSSARY

DCSLOG: Deputy Chief of Staff for Logistics

DCSOPS: Deputy Chief of Staff for Operations

FAST: CINCUSAREUR's Force Analysis System

JDS: Joint Deployment System

JOPS: Joint Operation Planning System

MCRR: Movement Control and Readiness Reporting System

MOB/ODEE: Mobility and Operational Deployment Evaluator

PEPA: Personnel, Equipment, Petroleum, and Ammunition Status Codes.

TOE: Table of Organization and Equipment

TPFDD: Time Phased Force Deployment Data

UTACCS: USAREUR Tactical Command and Control System

WWMCCS: World Wide Military Command and Control System

DEGRADED STATES VULNERABILITY METHODOLOGY

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Dr. Michael W. Starks
US Army Ballistic Research Laboratory

I. Introduction

In 1988, the Ballistic Research Laboratory (BRL) and the Army Materiel Systems Analysis Activity (AMSAA) began a joint program to develop improved metrics for expressing the results of vulnerability assessments, especially of ground combat vehicles. This report documents our first steps towards that goal.

Traditional tank vulnerability calculations have made use of a mapping procedure called damage assessment lists (DALs) or standard damage assessment lists (SDALs). A DAL maps killed components and sets of components into degradation of combat utility (DCU). It has been known for a number of years[1] that the use of DALs in the process of developing vulnerability measures of effectiveness is conceptually and mathematically problematic.

More recently, the original tank DAL[2] has been updated under the auspices of project Chicken Little.[3] This recent work led to renewed focus on the problems associated with DALs[4], and to a

1. J.R. Rapp, "An Investigation of Alternative Methods for Estimating Armored Vehicle Vulnerability," USA Ballistic Research Laboratory, Technical Report No. BRL-MR-03290, July 1983, (UNCLASSIFIED).

2. Canadian Armament Research and Development Establishment, "Tripartite Anti-Tank Trials and Lethality Evaluation, Part 1," November 1959, (UNCLASSIFIED).

3. G.A. Zeller, B.F. Armendt, "Updating the Standard Damage Assessment List (SDAL) for Tanks: Underlying Philosophy and Final Results," ASI Report 87-02, 31 July 1987, (UNCLASSIFIED).

4. M.W. Starks, "New Foundations for Tank Vulnerability Analysis," *The Proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association (ADPA)*, held at the Naval Ocean Systems Center, San Diego, CA, 10-12 May 1988, (UNCLASSIFIED).

proposal for their wholesale elimination from the process of vulnerability analysis in favor of a methodology which yields probabilities that a tank is in various degraded states.

Specific problems with the DAL process that have been discussed over the last decade include the following. The DCU estimates developed in the DAL process, defined as expected loss of function values, are typically used as if they reflected probabilities of no capability. A second problem is the use of probability mathematics for combining quantities which are not probabilities. Third, DALs have traditionally been developed by conclaves of experts who must mentally integrate over all possible combat missions, combining the effect of damage on all these missions into a single Mobility (M) and a single Firepower (F) DCU estimate. There are several problems with this sort of process. Mental integration is not a well defined analytical process and should be replaced by explicit integration where possible. Moreover, the set of all possible missions countenanced by today's doctrine may not be appropriate for tomorrow's. Finally, we believe the DAL values for the M and F functions are too slender a base on which to correctly erect the whole edifice of item and force-level modeling. There may have been justification for this oversimplified approach in an era of limited computational capability; today we can clearly do better.

The purpose of this paper is to present an overview of a pilot implementation of the degraded states methodology for the Abrams tank. A secondary purpose is to present examples typical of our results. These include results on traditional DAL-based vulnerability metrics, results using the degraded states methodology and a comparison of the two.

II. Approach

The pilot program was divided into two phases. Phase 1 centered on the comparison of the results calculated from existing M1A1 tank DALs, while Phase 2 was the development of the new Degraded States Vulnerability approach. In both phases, the methodology used was an adapted form of BRL's current Monte Carlo vulnerability code for point burst modeling, SQuASH (Stochastic

Quantitative Analysis of System Hierarchies)[5 6], developed by the Vulnerability Methodology Branch (VMB) of the BRL. For this analysis, only a portion of the SQuASH program was required, specifically, the sections which contain the information needed to make loss of combat function evaluations. This version, referred to as "SQuASHed", was used as the starting point for the development of the new methodology. A discussion of the model will not be included here as there are several published reports.

Forty-three damage states were obtained from the BRL-VMB, representing forty-three predictive shots calculated using the main SQuASH program. There were one thousand Monte Carlo trials run for each shot. These damage states contain the components which were killed in each Monte Carlo iteration for each shot. Using these damage states as input to the "SQuASHed" code, mean M, F, K and M/F values were calculated using the DAL methodology. Also, degraded states probabilities were calculated using the same input.

III. Methodology

1. M1A1 Damage Assessment Lists

The CARDE trials damage assessment list was taken from Tables E-1, E-2 and E-3 of the Zeller-Armendt report (reference 3). The current Abrams DAL, referred to in this report as the M1A1 DAL, was obtained from the BRL-VMB. No changes were required for use in this analysis.

A DAL based on the Chicken Little data had to be developed in the appropriate format. Using Table 2 ("Averaged Standard Damage Assessment List for Turreted, Gun Tanks") from the previously referenced Zeller-Armendt report, a DAL was adapted, employing all applicable data (e.g. ignoring autoloader data as no autoloader exists on the current M1A1). Prior to the development of the Chicken Little data, loss of critical components,

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5. Aivars Ozolins, "Stochastic High-Resolution Vulnerability Simulation for Live-Fire Programs," *The Proceedings of the Tenth Annual Symposium on Survivability and Vulnerability of the American Defense Preparedness Association (ADPA)*, held at the Naval Ocean Systems Center, San Diego, CA, 10-12 May 1988, (UNCLASSIFIED).

6. Paul H. Deitz, Aivars Ozolins, "Computer Simulations of the Abrams Live-Fire Field Testing," presented at the Army Operations Research Symposium XXVII, Ft. Lee, VA, 12-13 October 1988, (UNCLASSIFIED).

such as main armament or engine, were given a DCU value of 1.0 for firepower or mobility, respectively. Since the Chicken Little data represented all possible tank missions, it was argued that a certain percentage, in this case 15%, of those missions could still be accomplished without such components. Therefore, a DCU value of 0.85, instead of 1.0, was assigned to these critical components. To mitigate this controversial assumption, a fourth DAL was created for the comparisons, specifically a normalized Chicken Little DAL. We normalized by increasing the DCU value from 0.85 to 1.0, and subsequently, increasing all DCU values by the same percentage (0.15/0.85 = 0.176). Four sets of runs were made with "SQuASHed", using each of the DALs discussed, for the forty-three shots analyzed.

2. Development of Degraded States

The tradition has long been to describe vehicle loss of function in terms of mobility and firepower. For the new approach, a more robust set of metrics was developed. The functions of the M1A1 tank were divided into five subsystems: mobility, firepower, acquisition, crew, and communication. Each subsystem was further divided into a number of degraded states which described damaged, but functional, states of the tank. Each state was assigned an appropriate alphanumeric name. For example, M2 is the name given to the degraded mobility state defined as a significant reduction of speed. Each subsystem contains a "no damage" state and a series of degraded states. Within all the subsystems, except crew, combinations of degraded states can occur. For example, in firepower, an F9 degraded state exists. This degraded state represents a combination of three other degraded states: unable to fire on the move (F2), increased time to fire (F3), and reduced delivery accuracy (F4). In order for F9 to occur, F2 and F3 and F4 must all occur. For each subsystem combination, all listed, individual degraded states must occur for the combination to be realized. A complete list of the subsystems and their degraded states can be found in Table 1. This list was developed jointly by AMSAA and BRL analysts. The total number of combinations that are possible was calculated by multiplying the number of degraded states within each subsystem. This is shown at the bottom of Table 1.

Our next step was to develop mathematical fault trees to represent the degraded states. These fault trees consisted of critical M1A1 tank components that, if killed, would result in that particular degraded state. A degraded state is achieved if at least one interrupted path from top to bottom exists in the fault tree. Fault tree configurations can be described as having components arranged in series, or in parallel, or as some combination of the two. If listed in series, the loss of any component would result in a broken path whereas those components listed in parallel meant all had to be killed in order to cut that path. A list of approximately five hundred critical components and systems used in the M1A1 criticality analysis

TABLE 1. LIST OF M1A1 DEGRADED STATES

Subsystem Mobility	M0 -	No mobility damage
	M1 -	Reduced speed (slight)
	M2 -	Reduced speed (significant)
	M3 -	Stop after time t
	M4 -	Total immobilization
	M5 -	M1 + M3
	M6 -	M2 + M3
Subsystem Firepower	F0 -	No firepower damage
	F1 -	Loss of main armament
	F2 -	Unable to fire on the move
	F3 -	Increased time to fire
	F4 -	Reduced delivery accuracy (vs all targets)
	F5 -	Loss of secondary armament
	F6 -	F2 + F3
	F7 -	F2 + F4
	F8 -	F3 + F4
	F9 -	F2 + F3 + F4
	F10 -	F2 + F5
	F11 -	F3 + F5
	F12 -	F4 + F5
	F13 -	F2 + F3 + F4 + F5
	F14 -	F2 + F3 + F5
	F15 -	F2 + F4 + F5
	F16 -	F3 + F4 + F5
	F17 -	F1 + F5 (total loss of firepower)
Subsystem Acquisition	A0 -	No acquisition damage
	A1 -	Reduced acquisition capability
	A2 -	Unable to acquire while moving
	A3 -	A1 + A2
Subsystem Crew	C0 -	0 crew casualties
	C1 -	1 crew casualty
	C2 -	2 crew casualties
	C3 -	3 crew casualties
	C4 -	4 crew casualties
Subsystem Communication	X0 -	No communication damage
	X1 -	No internal communication
	X2 -	No external communication > 300 feet
	X3 -	No external communication
	X4 -	X1 + X2
	X5 -	X1 + X3

Combinations: M(0-6) F(0-17) A(0-3) C(0-4) X(0-5)
7 x 18 x 4 x 5 x 6 = 15,120 states

performed by the BRL-VMB[7] was used as the starting point for these fault trees. Once initial strawman trees were completed for all the degraded states within the five subsystems, discussions were held with appropriate personnel at BRL, AMSAA, the US Army Ordnance Center and School (USAOC&S) and the US Army Armor Center and School (USAAC&S). Comments and changes from these groups were incorporated and the final lists of components compiled for each degraded state. It should be noted that the individual trees are not mutually exclusive. A component could affect more than one fault tree within a subsystem, therefore, combinations of individual states are also considered (see Table 1).

After the fault trees were developed, it was necessary to incorporate them into the "SQuASHed" code. Using the BRL-VMB's Interactive Criticality Evaluator (ICE) program, the fault trees were translated into FORTRAN statements, known as SHOTPK equations, which represent the mathematics of the fault tree. Within the equation each component is assigned a SHOTPK variable (the same as the association table number for that component). The equation's mathematical expressions depict the appropriate Boolean operation for each component, i.e. series or parallel. The individual component is evaluated to determine if it has been killed. A "1" indicates the component was killed by the shot, while a "0" means the component was undamaged (read from the "Damage.States" file). The entire equation is then evaluated to determine if the degraded state was achieved. A "1" indicates the tree was cut and therefore, the state achieved. Otherwise, the equation yields a "0" and the fault tree was uncut. Within each subsystem, one state is achieved; the results of all five subsystems represent the degraded state of the tank for that iteration.

IV. Results

For purposes of this paper, only a small sample of results from this pilot program will be presented. The complete set of results and their corresponding detailed discussions are contained in a BRL technical report.[8]

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7. Joseph J. Ploskonka, Theodore M. Muehl, Cynthia J. Dively, "Criticality Analysis of the M1A1 Tank," US Army Ballistic Research Laboratory Memorandum Report No. BRL-MR-3671, June 1988, (UNCLASSIFIED).

8. John M. Abell, Lisa K. Roach, Michael W. Starks, "Degraded States Vulnerability Analysis," USA Ballistic Research Laboratory, Technical Report No. 3010, June 1989, UNCLASSIFIED.

1. **DAL to DAL Comparisons**

The mean DCU value (averaged over 1000 iterations) for M, F, and M/F was captured for each of the four DALs for all forty-three shots. These values were tabulated in bar charts to allow for comparisons. In general, the Chicken Little DALs (normalized and non-normalized) and the M1A1 DAL gave the higher values and the CARDE DAL the lower. This was expected since the Chicken Little DALs were recently compiled and the M1A1 DAL is a CARDE update to include M1A1 components. Differences between the Chicken Little DALs and the M1A1 DAL were small; in general, the Chicken Little DAL DCU values were slightly larger. Overall, the difference between any two DALs was no larger than about 0.10 for any kill criterion.

2. **Average DAL to Average DAL Comparisons**

As an additional comparison of the four DALs, the M, F and M/F values were averaged over the forty-three shots. These values and their standard deviations are presented in Table 2 (the DAL titled ABRAMS update is the M1A1 DAL discussed in this paper). In this comparison, the difference between the M1A1 DAL and the two Chicken Little DALs was negligible. Further, even though the difference between the CARDE and the other DALs was slightly larger, the CARDE DAL should be considered a worst case as it would not be used for analysis of modern tanks without appropriate updates.

3. **Results of Degraded States**

The Degraded States Vulnerability approach was applied to the forty-three shots. For each iteration within a specific shot, the degraded states combination (one degraded state from each subsystem) was calculated; the rate of occurrence for all realized combinations was then calculated over the 1000 iterations. Because this procedure correctly captures any existing correlations across the five subsystems considered, it is the highest resolution form of output available from the degraded states methodology. Information in this form might prove useful to high resolution wargamers or to analysts conducting detailed vulnerability reduction studies of US materiel. However, not every user of VLD's estimates is equipped to handle 15,120 possible outcomes.

For this reason, we also calculated the frequency of occurrence of the various states within the five subsystems taken separately. This data was generated for use in comparisons that will be discussed later in this report. Use of the separate probabilities implicitly requires an independence assumption that is probably not correct in detail. It will be a subject of further work to determine whether, or to what extent, such an independence assumption is plausible. We exhibit the subsystem distributions here for the following reason. Such an assumption is

TABLE 2. AVERAGE DAL COMPARISONS

Average over 43 shots								
	CARDE		ABRAMS		CHICKEN LITTLE		CHICKEN LITTLE (N)	
	mean	std. dev.	mean	std. dev.	mean	std. dev.	mean	std. dev.
M	0.45	0.25	0.50	0.24	0.52	0.25	0.54	0.26
F	0.51	0.23	0.58	0.24	0.63	0.25	0.64	0.26
M/F	0.61	0.26	0.70	0.24	0.69	0.26	0.70	0.26

required if the magnitude of degraded states probabilities are to be coherently compared to DAL DCU estimates.

As indicated above, the total number of degraded states combinations was 15,120. For the individual shots, the number of realized combinations ranged from one to forty-three. The damage resulting from any one shot occurred for a specific set of impact conditions thereby reducing the number of vulnerable components likely to be hit. As a result, the number of possible degraded states combinations that could occur was also reduced. In general, for each shot, a few combinations were realized 10% or more of the time, while the remaining occurred less frequently. The same component or set of components were killed in the majority of Monte Carlo iterations causing the same degraded states combination(s) to occur. Occasionally, different components were killed resulting in the occurrence of another combination. We reserve further discussion of the individual shot degraded states results for the BRL technical report (referenced above).

4. Average Degraded States Calculations

In addition to calculating the individual shot data just discussed, the total number of realized combinations over all forty-three shots was determined along with each combination's probability of occurrence over that sample. For this analysis, 123 unique degraded states combinations were realized. The probability of a combination occurring was calculated by dividing the number of combination occurrences by the total possible occurrences (43 shots X 1000 iterations = 43000). The probability of no damage to any subsystem was 0.29. Of the 122 remaining combinations, the probability of occurrence of each state was 0.06 or less. This type of data was also determined for the five subsystems individually and for a Mobility-Firepower combination. (The latter was calculated to determine what combinations of Mobility or Firepower had occurred.)

It must be acknowledged that globally averaged information of this kind does not correspond to physically realistic initial conditions since many different kill mechanisms and hit points were used. Still, the calculation is of some interest for several reasons. First, the calculation gives us at least some idea of what fraction of the 15,120 states might actually be realized in a practical view-average analysis. Second, as will be seen below, the global average provides us with a useful means of globally comparing DAL outcomes with degraded states outcomes.

5. Degraded States to DAL Comparisons

The final phase of our pilot program required comparing degraded states results to DAL results. Since all four DALs gave essentially the same results, only one DAL, the Chicken Little (normalized), was selected for the comparison. It should be noted that this is intrinsically an apples/oranges type of comparison since DAL results are calculated by surviving DCU values and the degraded states results are true mathematical probabilities. Also, the latter approach provides acquisition, crew and communications results separately whereas the former lumps them into the mobility (M) and firepower (F) values. Note that initial PKs were calculated by the BRL-VMB for some shots in order to represent a predicted hit on the ammunition. Since the Degraded States approach doesn't yet explicitly handle ammunition, the initial PKs were changed to zeros and the affected shots were rerun with the Chicken Little (normalized) DAL for this comparison. To make the comparison more accurate, additional DAL runs (without the initial PKs) were made by removing the contribution to lethality of the crew, communications, and then both. For each shot, the sum of the probabilities of the individual degraded states realized in each of the five subsystems was compared to the M and F values from the four Chicken Little (normalized) DAL runs.

There were four classes of outcomes that emerged from these comparisons. Here the term "agreement" means the numerical difference is approximately 0.10 or less. First, there were cases where the degraded states result disagreed with the typical DAL outcome for both mobility and firepower, but agreement was reached when the crew and communications contributions were removed from the DAL. This occurred in eight of the forty-three shots Note that with the Degraded States approach the ability exists to average/sum late in the analytical process. With the DAL process, higher resolution information cannot be recovered because it is aggregated away early in the process. In the second class of outcomes the two results showed immediate agreement for mobility and firepower. Although there was immediate agreement, the degraded states results gave a fuller picture of the damage to the tank (true for all the comparisons). Twenty-five shots fell into the second class. Eight shots formed the third class of outcomes which was a combination of the first two. That is, the mobility comparison was of one class and the firepower the other. Finally, there were two shots that showed total disagreement.

In summary, the two vulnerability approaches showed reasonable comparability in magnitude between the results because the majority of components killed in these shots gave DAL values of approximately 1.00. In approximately half of the shots, the agreement was seen immediately. In the other half, the crew and communications contributions were removed from the DAL results in order to reach good agreement. There were two shots where agreement was never reached because of the particular components killed.

6. Average Degraded States vs Average DAL Comparison

An average M and F value, over the forty-three shots, was calculated for each of the four sets of Chicken Little (normalized) DAL runs made for the shot to shot comparisons; these average values were then compared to the average degraded states values. The results of this comparison are presented in Table 3.

Some explanation is needed for the format of Table 3. A verbal description of the realized degraded states is provided in the left most column. The first column of numbers in the table represents the degraded states probabilities while the remaining four columns contain DAL results. Within each subsystem, the degraded states values are read top to bottom along with the corresponding verbal description. If a combination of individual degraded states occurred, then the verbal descriptions are listed sequentially with the associated probability found next to the last verbal entry. These individual probabilities are summed to obtain the total probability of kill for that subsystem. The summed value is then compared to the DAL results. This procedure is consistent with the DAL's intended purpose of capturing both missions that cannot be executed at all and missions that can be done "less well". All four DAL results are labeled appropriately and are read from left to right starting with the value next to the summed degraded states probability for that subsystem.

In both the mobility and firepower subsystems, the results show immediate agreement (second class). Also, when the crew and communications contributions are removed from the DAL results, a closer agreement is reached (first class). The more robust degraded states results show how the DAL results can be very misleading with regard to the way they are typically used in force-on-force modeling. For example, the DAL mobility result (0.51) would be used as if 51 percent of the tanks were totally immobilized whereas only 17 percent are actually immobilized according to the degraded states result, 19 percent would have significant speed reductions, and 2 percent would have slight reductions. There is every reason to expect that these differences could be very significant in terms of wargame outcome. Similar arguments can be made for the firepower subsystem. Results for the remaining three subsystems (acquisition, crew and communications) provide information that cannot be extracted from DAL results, and which will often prove useful for BRL customers.

As a final step in the analysis, the average degraded states results were reduced to a single value (M, F, and M or F) for comparison with the average DAL results. This comparison is presented in Table 4. The top set of degraded states results (direct hardware only) involve only the mobility and firepower subsystems (see Table 1). The second set (related hardware and crew) involve all the subsystems in order to include the information normally included in the DAL values. The M value was calculated by summing the probabilities of the mobility, crew and

TABLE 3. AVERAGE DAL AND AVERAGE DEGRADED STATES COMPARISONS

Average over 43 shots

DEGRADED STATES		SDAL			
		CL(N)	w/o crew	w/o commo	w/o both
MOBILITY					
Reduced speed, significant	0.19				
Total immobilization	0.17				
Reduced speed, slight	0.02				
	0.38	0.51	0.46	0.46	0.40
FIREPOWER					
Loss of main armament	0.34				
Unable to fire on the move					
Increased time to fire					
Reduced delivery accuracy	0.14				
Increased time to fire					
Reduced delivery accuracy	0.05				
Loss of main armament					
Loss of secondary armament	0.01				
	0.54	0.58	0.56	0.57	0.53
ACQUISITION					
Reduced acquisition capability					
Unable to acquire while moving	0.52				
Reduced acquisition capability	0.05				
	0.57	?	?	?	?
CREW					
One crew casualty	0.20				
Two crew casualties	0.15				
Three crew casualties	0.03				
	0.38	?		?	?
COMMO					
No internal communication					
No external communication	0.33				
No external communication	0.01				
	0.34	?	?		?

TABLE 4: SINGLE AVERAGE DAL VALUE AND SINGLE AVERAGE DEGRADED STATES VALUE — COMPARISON

Average Degraded States vs Average DAL Comparisons

	M	F	M or F
Degraded States (direct hardware only)	0.38	0.54	0.60
DAL	0.51	0.58	0.65
Degraded States (related hardware and crew)	0.64	0.65	0.71

communications subsystems (excluding the no damage occurrences). The firepower, acquisition, crew and communications subsystems were included in the F value. The M or F value included all five subsystems (1 - no damage). The degraded states results bracket the DAL results which show that it is possible to reduce to a single vulnerability estimate for cases when that type of metric is required. This is an important finding in terms of the analytical community's transition from DAL-based metrics to degraded states metrics.

V. Summary

The proposed degraded states vulnerability approach provides a robust and mathematically correct set of metrics for use in vulnerability analyses. As discussed in the previous sections, the results obtained from the degraded states approach bracket the results obtained from the DAL as illustrated in Table 4. When adopted, our approach will provide both a detailed, illuminating account of vehicle vulnerability and an aggregated set of metrics analogous to the traditional set.

Because of the promise shown by the degraded states method, additional work is underway. First, the predictive live-fire shot data used in this analysis represent only selected shots versus the target vehicle. With this in mind, the BRL-VMB is updating the SQuASH model to compute view average values for M and F. Once this is complete, the degraded states vulnerability approach will be used to allow calculation of the view average data for degraded states. This will provide data in the form normally required by the users of the vulnerability estimates. This data will also support AMSAA in a demonstration of the new set of metrics in force-level modeling.

Second, the set of forty-three shots used in this analysis is a relatively narrow sample set. Analysis of other vehicles using this approach will provide a broader spectrum of results for determining its ultimate usefulness. Work is underway to define degraded but operational states for both the Bradley IFV and a Soviet/Warsaw Pact tank. Results of these analyses will provide a fuller insight into the utility of the degraded states vulnerability approach.

If work proceeds as expected on the two tasks just mentioned, then sufficient information should be in hand during calendar year 1989 for the Army to declare its intent to drop its reliance on the SDAL methodology in favor of the degraded states approach. We believe that both the plausibility and the promise of that approach have been demonstrated here.

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METHODOLOGY FOR SURVIVABILITY ANALYSIS
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1. INTRODUCTION

The purpose of this paper is to delineate an approach and methodology for the survivability assessment of blue penetrator missiles when targeted by red threat surface-to-air (SAM) interceptor missile systems. The U.S. Army Missile Command (MICOM) at Redstone Arsenal, Alabama required a methodology for survivability assessments of blue penetrator missiles when attacked by red threat missile systems. This methodology for survivability analysis was required for both the prelaunch/post launch, and in-flight phases. The in-flight phase is concerned with one-on-one and many-on-many analysis capabilities and procedures. Both offensive deep attack systems and defensive anti-tactical (ATM) missile systems were to be analyzed.

2. BACKGROUND

A Fire Support Mission Area Analysis (FSMAA) was conducted in the late seventies by the Fort Sill Artillery School. The analysts identified a need to fire long range surface-to-surface missiles into hostile second echelon targets. Obvious benefits would be target attrition, attacking force delays, disruption, and the prevention of close-in-battle area massing of forces. Other activities that supported the second echelon attack doctrine were: (1) The Forward of the Forward Edge of the Battle Area (FOFEBA) study, (2) the Assault Breaker Program, and (3) a Special Task Force (STF) Study Group at Fort Sill, Oklahoma.

3. OBJECTIVE

The objective is to provide a procedure for conducting survivability analysis in support of major activities, such as concept formulation, proposal evaluation and full scale development programs. The analysis approach and methodology is to consider both the materiel and operational factors that affect survivability.

4. APPROACH

Detailed mathematical models which estimate the performance and physics of flight are used for assessing in-flight survivability of penetrator missiles. These models consider: (1) the red threat missile characteristics, (2) the penetrator characteristics, and (3) threat doctrine, tactics, and operational environments in one-on-one and many-on many scenarios. The one-on-one analysis simulates the detailed performance characteristics of the penetrator and the red threat surface-to-air missile (SAM) defense systems. The results of this one-on-one analysis then supports the many-on-many analysis which simulates the synergistic effects associated with both the penetrator and the red threat SAMs operating with other complimentary systems. Examples of mathematical models that are used to derive the results are discussed and described.

5. METHODOLOGY FOR ONE-ON-ONE ANALYSIS

There are several similar computer simulation models that are currently used for one-on-one survivability methodology. The Penetration Assessment of Terminal Engagements (PASTE) model is described below as an example.

5.1 APPLICATION

The one-on-one simulation models the blue penetration and red SAM defense interaction in a one-on-one battle. Table 1.0 summarizes the characteristics and typical applications of the one-on-one analysis approach. The one-on-one model reduces the complexity of the survivability analysis by considering the interaction of a single blue penetrator missile attacking a single red SAM site. This allows detailed investigation of critical performance parameters, such as blue penetrator and red SAM flight dynamics, engagement geometry, penetrator vulnerability, SAM interceptor lethality, penetrator signatures, and operational environments (e.g, nuclear effects and electronic countermeasures).

Table 1.0 One-On-One Model

.MODELS DETAILED PHYSICAL REPRESENTATION OF WEAPON SYSTEM
- DETECTION PROCESS
- SIGNATURE
- TARGET AND INTERCEPTOR FLIGHT DYNAMICS
- ENGAGEMENT GEOMETRY
- TARGET VULNERABLILTY

.APPLICATIONS
- ENGINEERING TRADEOFFS
- TACTICS AND RULES ENGAGEMENT

.MODEL SPECIFICS
- EXPLICITLY CAPUTURES THE PHYSICS OF THE AIR DEFENSE PROBLEM
- INTELLIGENCE DATA REQUIREMENTS DIRECTED TOWARD PHYSICAL CAPABILITIES OF WEAPON SYSTEMS
- USED FOR COMPUTING INPUTS TO HIGHER-LEVEL MANY-ON-MANY OR FORCE-ON-FORCE MODELS
- GENERALLY FAVORS "QUALITY" CANDIDATE OVER "QUANTITY" CANDIDATE
- MORE DATA AVAILABLE TO VALIDATE ONE-ON-ONE MODEL

The primary objective of the one-on-one analysis is to determine the blue penetrator survivability in a one-versus-one battle as the blue penetrator attacks a single target defended by single SAM site. Repeated application yields defended area footprints which represent the capability of an array of SAM sites to sucessfully intercept the blue penetrator. The one-on-one model is particularly useful for performing sensitivity analyses on both the penetrator and SAM defense capabilities.

Another important application of the one-on-one analysis is computing inputs to higher-level many-on-many or force-on-force models. The output results of the one-on-one analysis will be aggregated and incorporated into a many-on-many model in order to enhance the efficiency and broaden the scope of the many-on-many analysis.

5.2 MEASURES OF SURVIVAL

It is generally recognized that models can be used to compare one system with another but that difficulty can arise when trying to compute an absolute measure of merit. Therefore, no attempt is made to compute an absolute measure of survival; however, four measures of survival have been selected at the one-on-one level that provide significant insight into the expected penetrator inflight survivability against a designated SAM threat. These measures of survival are:

- SAM Defended Area Footprint
- SAM Battlespace
- SAM Intercept Envelope.
- SAM Lethal Area

Each of these measures is described in the following sections.

5.2.1 SAM DEFENDED AREA FOOTPRINTS

A defended area footprint provides a measure of the SAM system's engagement capability against the blue penetrator missile in both self-defense and area defense roles. Results of the SAM engagement performance are presented either as miss distance or probability of kill (P_k). P_k results are generated based on blue penetrator missile vulnerablilty and SAM fuzing and warhead performance. Implicit in the footprints is the SAM radar and interceptor capability against the blue missile.

Footprints can be developed by moving SAM sites to cover all reasonable defensive positions about the target and calculating weapon survival for each site. From this data, equal probability weapon survival contours may be constructed as shown in Figure 1.0.

A SAM site located inside a probability of survival countour $P_S \lesssim .4$ would have a $P_k \gtrsim .6$ of killing the weapon during its attack on the target from the specified direction. Defended area footprints are typically generated to study the effect on survivability of parameters, such as blue penetrator trajectory, nose on radar cross section, or SAM site placement. In addition, footprints are very useful for planning raids on defended targets.

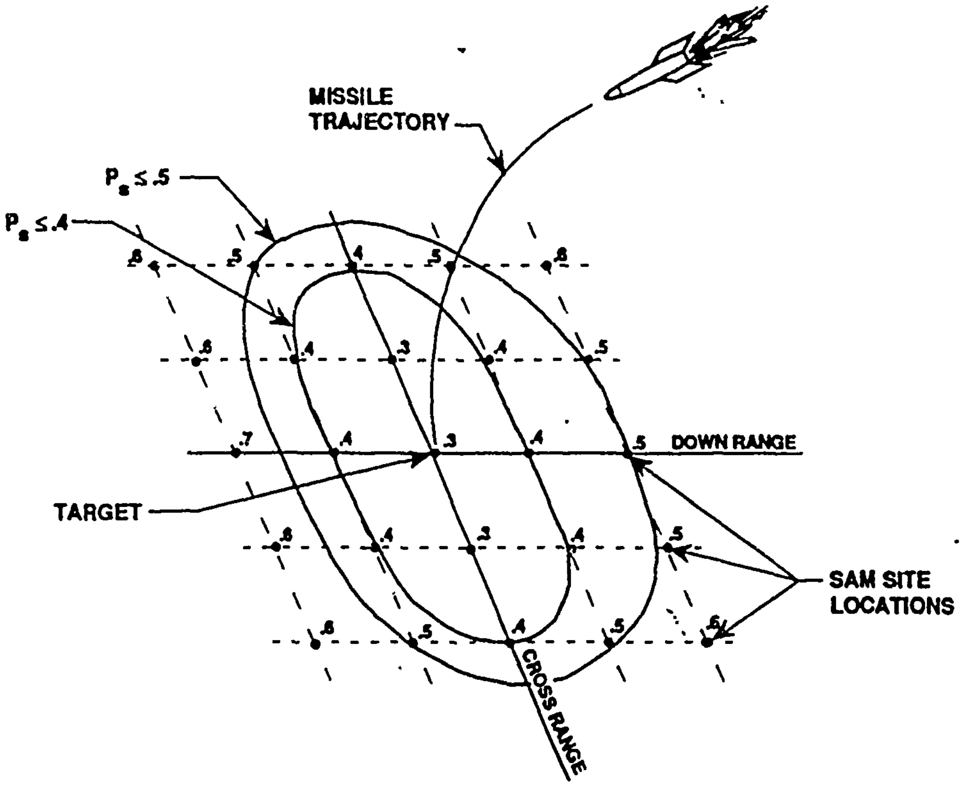

FIGURE 1.0 REPRESENTATIVE DEFENDED AREA FOOTPRINT

5.2.2 SAM BATTLESPACE

Figure 2.0 illustrates the events associated with the determination of defense battlespace. As shown, for a given radar cross section (RCS), the penetrator missile is detected by the surveillance radar at time T_1. Based on cueing from the surveillance radar, the engagement radar detects the penetrator at time T_2; interceptor launch occurs at time T_3 based on system reaction time and rules of engagement. The resulting battlespace is defined as time between interceptor launch and penetrator warhead event (T_4 $-T_3$). The larger the battlespace, the more time the defense has to plan and conduct engagements (e.g., shoot-look-shoot), and the more vulnerable the penetrator is to intercept.

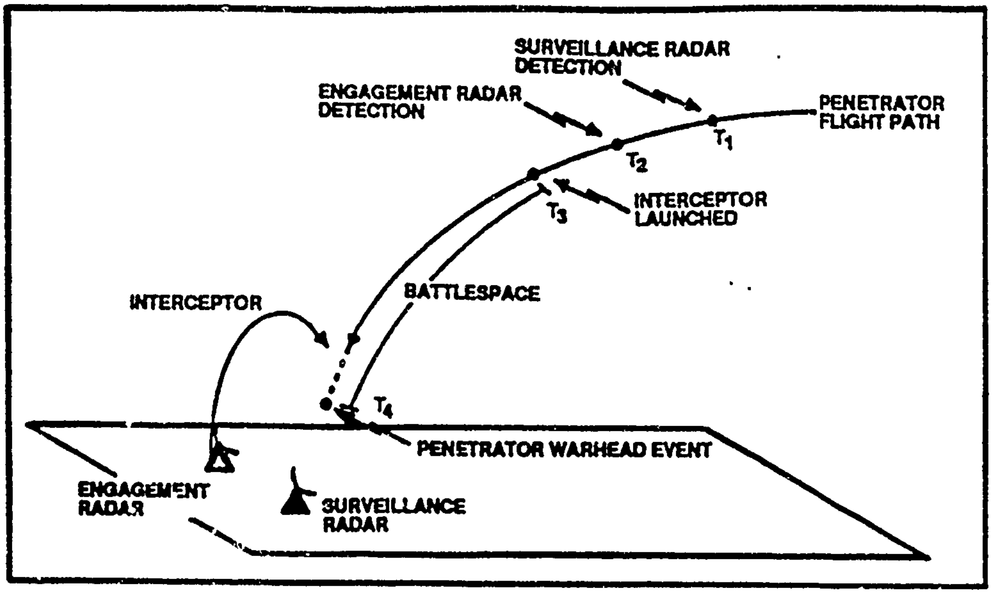

FIGURE 2.0 DEFENSE BATTLESPACE

5.2.3 SAM Intercept Envelope.

A SAM intercept envelope provides a measure of the engagement volume. The volumes are generated using essentially the same methodology as that used in generating the defended area footprints. However, where the footprint method uses the assessed SAM firing doctrine (typically shoot-look-shoot, and shoot at the first opportunity, in the absence of specific intelligence information), the intercept envelope method involves successive intercepts, each incremented by a fixed time, Dt.

Figure 3.a illustrates the methodology. As shown, the first interceptor is launched at the first opportunity, L_1; this potentially results in an intercept, I_1, which is recorded as a miss distance and/or P_k. The next launch attempt is delayed a fixed time, Dt, until L which potentially results in an intercept, I_2. This process is repeated until no further intercepts are possible.

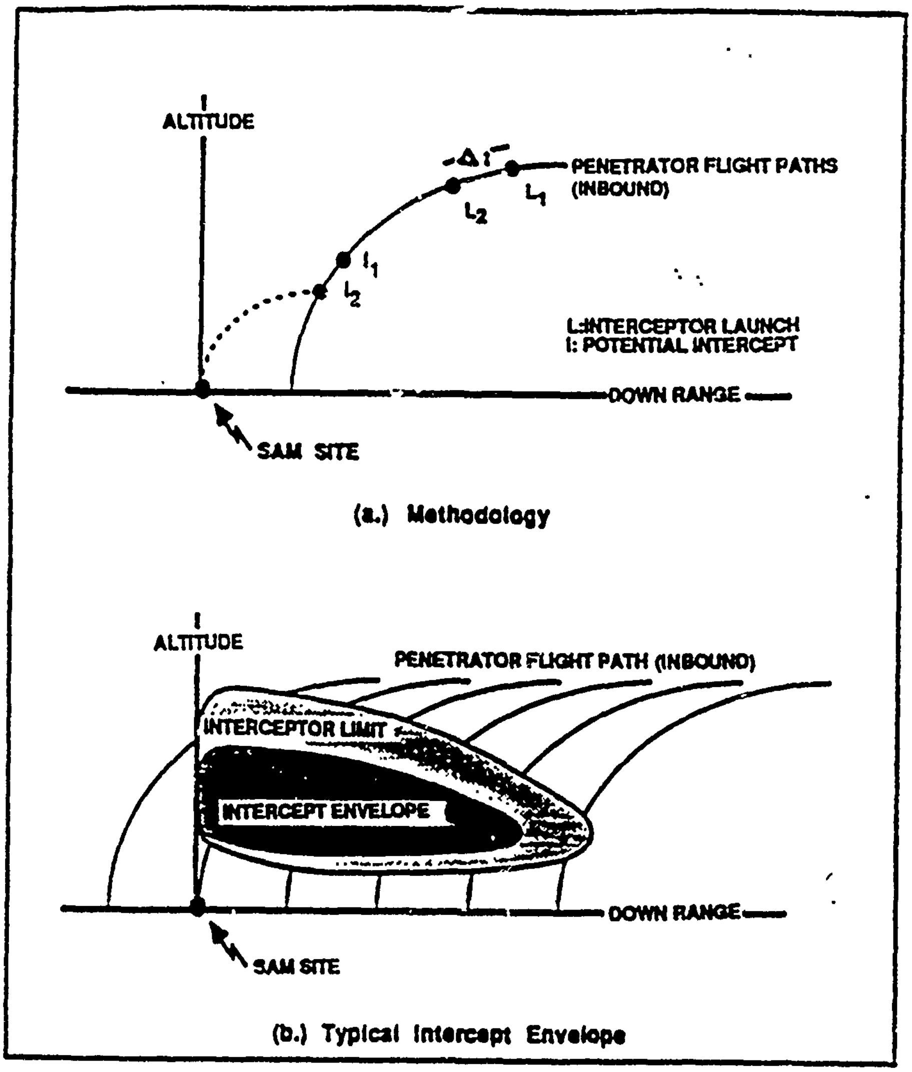

FIGURE 3.0 SAM INTERCEPT ENVELOPE

5.2.4 SAM Lethal Area

The concept of lethal area is used as a measure of effectiveness. The size of the SAMs lethal area is an indicator of its effectiveness. Lethal area is defined as the sum of the probabilities of kill for each site located on a specific grid times the area separating each site. For example: If there are n sites placed on a grid every 50km, then:

$$\text{Lethal Area} = (50)^2 \sum_{k=1}^{n} p$$

Where P is the k sites's probability of kill and 50 km is the equal distance separating each site. A relatively small lethal area indicates a high probability of survival for the penetrator.

5.3 PASTE MODEL OVERVIEW

The Penetration Assessment of Terminal Engagements (PASTE) model simulates the operational performance of SAM defense systems for one-on-one engagements.

Figure 4.0 shows that PASTE simulates all major SAM engagement elements and characteristics. Required inputs to the model include characteristics of the SAM defense, the penetrator (e.g., missile or aircraft) and the terrain. The model operates on these inputs to derive time-sequenced events of the engagement, and provides as output the expected number of SAM engagements, miss distance, probability of kill associated with each engagement, and cumulative probability of kill.

As noted, PASTE simulates, in detail, the time-sequenced events of the entire engagement process. These include: detection of the penetrator by a surveillance radar; acquisition and track by the engagement radar; and flyout and engagement by the SAM. At the end-game, PASTE models penetrator vulnerability and SAM warhead fuzing and fragmentation kill. The resulting output is the probability of penetrator survival for the given engagement condition.

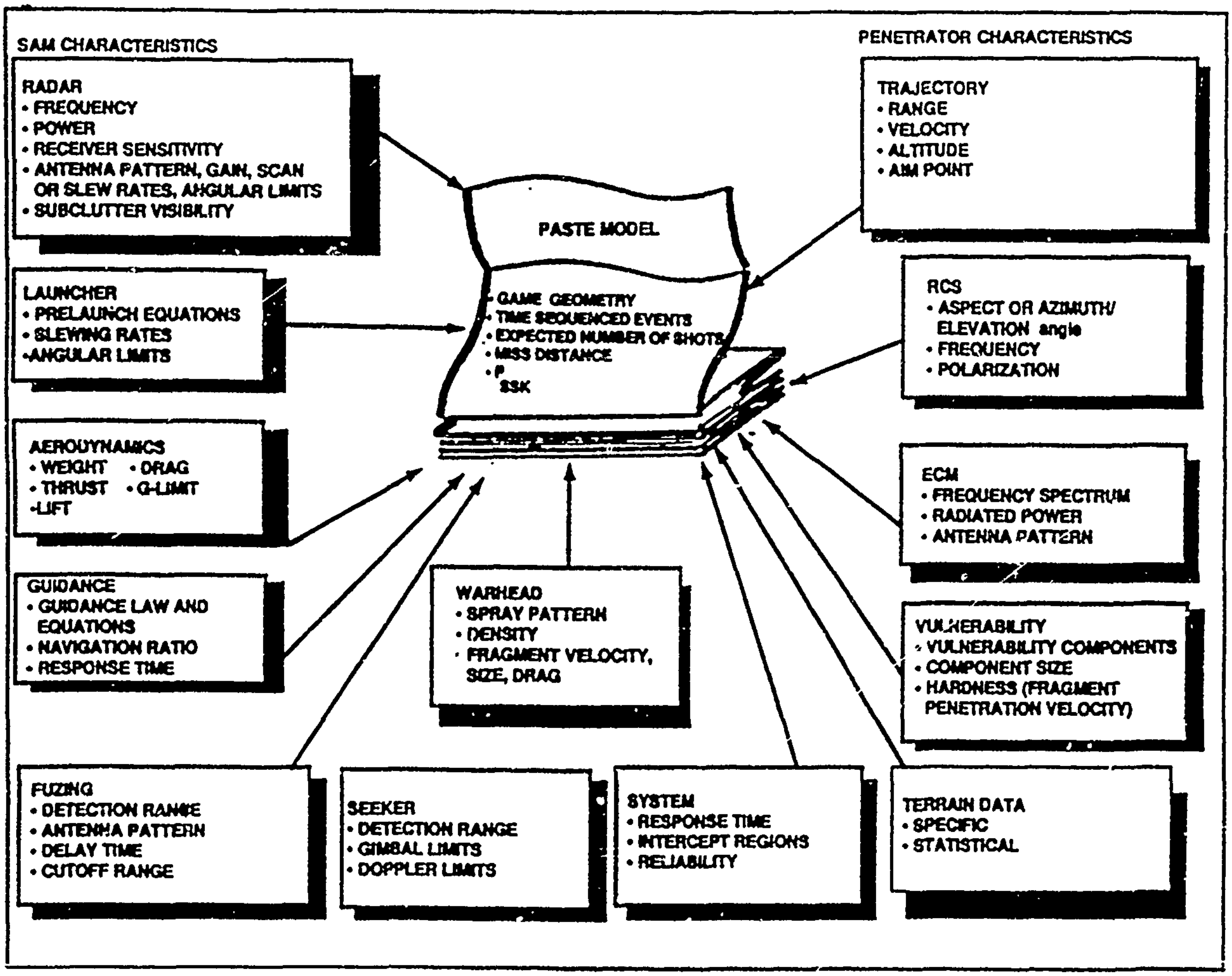

FIGURE 4.0 PASTE MODEL

For low-flying penetrators (e.g., cruise missiles, aircraft), PASTE simulates the effects of real terrain, either specifically or statistically. If the topography is known around a SAM site, the specific terrain data can be input to the model. Alternatively, the statistical terrain characteristics defining a particular geographical area can be used. Thus, the effects of terrain masking, clutter, and multipath on radar and seeker performance are explicitly modeled.

6. METHODOLOGY FOR MANY-ON-MANY ANALYSIS

This section discusses the need and application for many-on-many modeling and analysis in the evaluation of penetrator in-flight survivability. In addition, suggested measures of survival are presented for summarizing analysis results and the OASIS many-on-many engagement model is described.

6.1 APPLICATION

It is at the many-on-many level where the synergistic effects of both Blue and Red forces come into play, and where the broader aspects of the battle can be modeled and analyzed. In the case of penetrator in-flight survivability, the "broader aspects of the battle" involves modeling and analyzing: (1) the effects of penetrator and SAM defense deployment doctrine, mission, and tactics, (2) the synergisms accruing to a penetrator and the defense resulting from other blue penetrators and from an integrated SAM defense system, respectively, and (3) the effects of battle duration. Table 2.0 summarizes some key aspects of the many-on-many analysis approach.

Table 2.0 Many-On-Many Model

- **MODELS SYNERGISTIC EFFECTS OF AIR DEFENSE PROBLEM**
  - **OFFENSE/DEFENSE INTERACTION**
  - **OFFENSE/DEFENSE RESOURCE ALLOCATION**
  - **TACTICS**
  - **FIRING DOCTRINE**
  - **DECISION PROCESS**
  - **C^3**
  - **COUNTERMEASURES**
- **APPLICATIONS**
  - **BROADER ASPECTS OF AIR DEFENSE PROBLEM, e.g., EFFECTS OF DEPLOYMENT,**
  - **EMPLOYMENT DOCTRINE, MISSION, TACTICS**
  - **SYNERGISTIC EFFECTS OF BOTH ATTACKING AND DEFENDING SYSTEMS**
  - **QUANTITY VERSUS QUALITY TRADEOFFS**
- **MODEL SPECIFICS**
  - **REQUIRES MORE INTELLIGENCE DATA THAN ONE-ON-ONE, e.g., EMPLOYMENT DOCTRINE, ENGAGEMENT RULES, C^3**
  - **MORE ALTERNATIVES FOR MEASURES OF MERIT TO SUMMARIZE RESULTS**

The SAM defense problem is considerably different when the separate SAM systems are considered as performing as an integrated defense system. The one-on-one level is concerned primarily with analyzing the detailed performance of the systems. The many-on-many level is somewhat different for the survivability analysis approach. The many-on-many level addresses, for example, the effects of employment doctrine, engagement policy, tactics and command and control systems.

6.2 MEASURES OF MERIT

In selecting the measures of merit for the many-on-many analysis, care must be exercised in considering the way in which the measures influence the conclusions that are drawn. The following are suggested measures of merit for both the penetrator and the SAM defense:

PENETRATOR

- Penetrator Survivability (m/n)
  m = Penetrators arriving at target
  n = Penetrators launched
- SAM Defense Kills
- Ground Target Kills

SAM DEFENSE

- Penetrator Kills
- Number of Interceptors Used

6.3 OASIS OVERVIEW

OASIS is a time-sequenced many-on-many engagement simulation program which can be used for both conventional and nuclear analyses. Numerous offensive missiles, defensive interceptors, defensive radars and/or optical sensors, and target sets can be included in the engagement scenario, and various battle management schemes can be employed. Table 3.0 summarizes the features, nuclear effects modeled, and input and output of OASIS.

Nuclear environments modeled in OASIS include blast, thermal radiation, X-ray and neutron radiation, prompt and delayed gamma-ray radiation, blackout, electromagnetic pulse (EMP), nuclear cloud interactions, and a number of others. These environments are updated each time cycle, and their interaction with in-flight missiles is computed. The persistent endoatmospheric effects, such as blast, thermal radiation, and nuclear clouds are simulated in the program until such time as they become ineffective at damaging elements modeled in the simulation. Blackout environments are likewise simulated until they no longer perturb radar operation.

Table 3.0 OASIS Many-On-Many Engagement Model

FEATURES	NUCLEAR EFFECTS MODELED
. MANY-ON-MANY ENGAGEMENT SIMULATION . NUCLEAR EFFECTS ON ALL ELEMENTS . FLEXIBLE BATTLE MANAGEMENT LOGIC . REASONABLE RUN TIME	. BLAST . THERMAL . PROMPT AND DELAYED RADIATION . NEUTRONS, GAMMA-RAYS, X-RAYS . RADAR BLACKOUT . DUST CLOUDS
INPUTS	**OUTPUTS**
. PENETRATOR DATA (ONE-ON-ONE FOOTPRINTS, TRAJECTORIES, LAYDOWN, YIELDS, ETC.) . SAM STOCKPILE AND FLYOUT CHARACTERISTICS . RADAR CHARACTERISTICS . ACQUISITION AND TRACK REQUIREMENTS . SAM BATTLE MANAGEMENT LOGIC . NUCLEAR ENVIRONMENTS DATABASE . HARDNESS LEVELS OF ALL ELEMENTS	. PENETRATOR EFFECTIVENESS - TARGETS DESTROYED AND - MISSED - NUCLEAR ENVIRONMENTS AND FRACTRICIDE - COLLATERAL DAMAGE TO TARGETS . SAM EFFECTIVENESS - PENETRATORS INTERCEPTED AND MISSED - ENVIRONMENTS RECEIVED - RADAR BLACKOUT PROBLEMS

All elements in the engagement, including offensive penetrator missiles, defensive interceptors and radars, and ground targets are subjected to the nuclear environments, and are destroyed if the environments exceed the element nuclear hardness. When blackout reduces the signal to noise ratio (SNR) below the threshold level, the penetrator missile tracking is lost, and intercepts cannot be scheduled until the offensive missile is reacquired or handed off to another radar.

As the OASIS simulation proceeds, an engagemen history is output at each time step where significant events occur. At the completion of the OASIS run, a summary is output that gives performance statistics for the offensive penetrator missiles, defense system interceptors and radars, targets sets, and all other active battle elements.

7. METHODOLOGY FOR PRELAUNCH/POSTLAUNCH SURVIVABILITY

This section presents the approach and methodology for assessing the blue penetrator prelaunch/postlaunch survivability. The prelaunch/postlaunch survivability assessment focuses on the interaction of the penetrator and the threat element sets.

The penetrator launcher survivability against a backtrack threat is very dependent on the penetrator inflight signature and trajectory. A backtrack threat survivability assessment is required for each candidate penetrator concept.

7.1 PENETRATOR LAUNCHER THREAT ASSESSMENT

The threat assessment will analyze intelligence estimates of the threat to the penetrator launcher, and estimate assessed threat capabilities in the areas of reconnaissance, surveillance and target acquistion (RSTA) and counterforce assets. Both the prelaunch threat (e.g. deep attack weapons, ground forces) and postlaunch threat (counterfire) to penetrator survival will be addressed. Particular emphasis will be placed on characterizing threat response timelines; these timelines will be overlaid on penetrator operational timelines to assess its survival as a function of the operational timelines and tactics.

7.2 MISSILE TRAJECTORY BACKTRACK

Against a ballistic missile penetrator, a tactic the threat could potentially employ against the penetrator launcher would be to detect and track the missile early in its launch phase, and use the track data to predict the launch point by backtracking the missile trajectory. In such a tactic, the surveillance radar system would compute a launch point estimate (LPE) and then cue an appropriate counterbattery weapon system, with the objective to attack and destroy the penetrator launch vehicle before it could depart from (or move a substantial distance from) its launch position.

This backtrack tactic is illustrated in Figure 5.0 where the surveillance system is a ground-based counterbattery radar asset, and the counterbattery weapon system is a Short Range Ballistic Missile (SRBM).

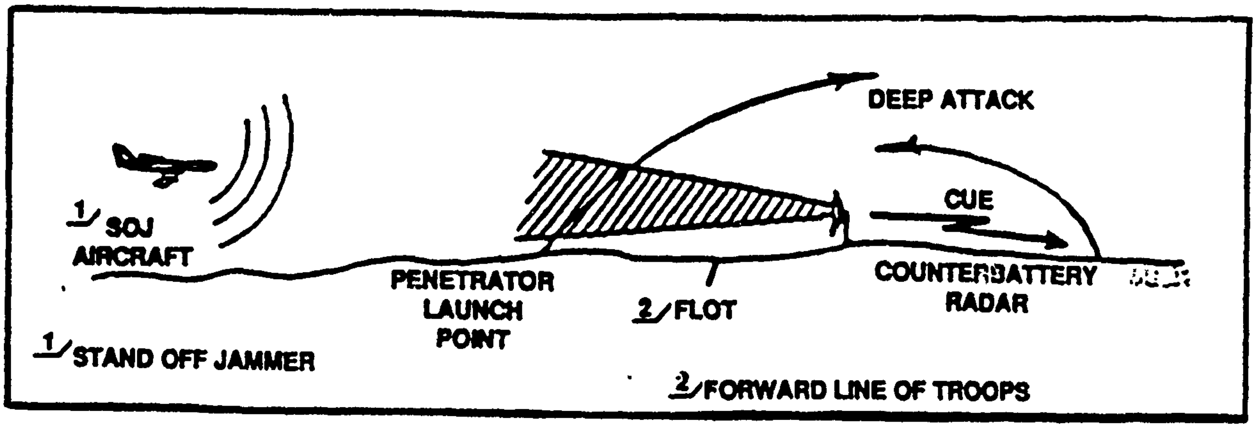

FIGURE 5-0 BACKTRACK SCENARIO

7.3 BACKTRACK CRITICAL ISSUES

There are a number of critical issues that make the implementation of the backtrack tactic a non-trivial problem for the defense.

- Early detection and backtrack of a high-velocity penetrator missile requires a high-performance radar specifically configured for the backtracking role.
- Dedicated communications and a quick-reaction weapon system are required in order to have any opportunity to kill the penetrator, with conventional weapons, since the penetrator will employ a shoot-and-scoot tactic.
- Penetrators will employ an offset maneuver in the launch phase which will greatly complicate the backtrack tactic.
- Electronic countermeasures (e.g., barrage noise jammers) can be used effectively against counterbattery radars.
- Penetrator set-back distances from the Forward Line of Troops (FLOT) can be increased, which greatly complicates both penetrator detection and launch point prediction accuracy for ground-based counterbattery radars.

These, and other pertinent critical issues will be analyzed to assess the impact of the backtrack tactic on penetrator launcher survivability.

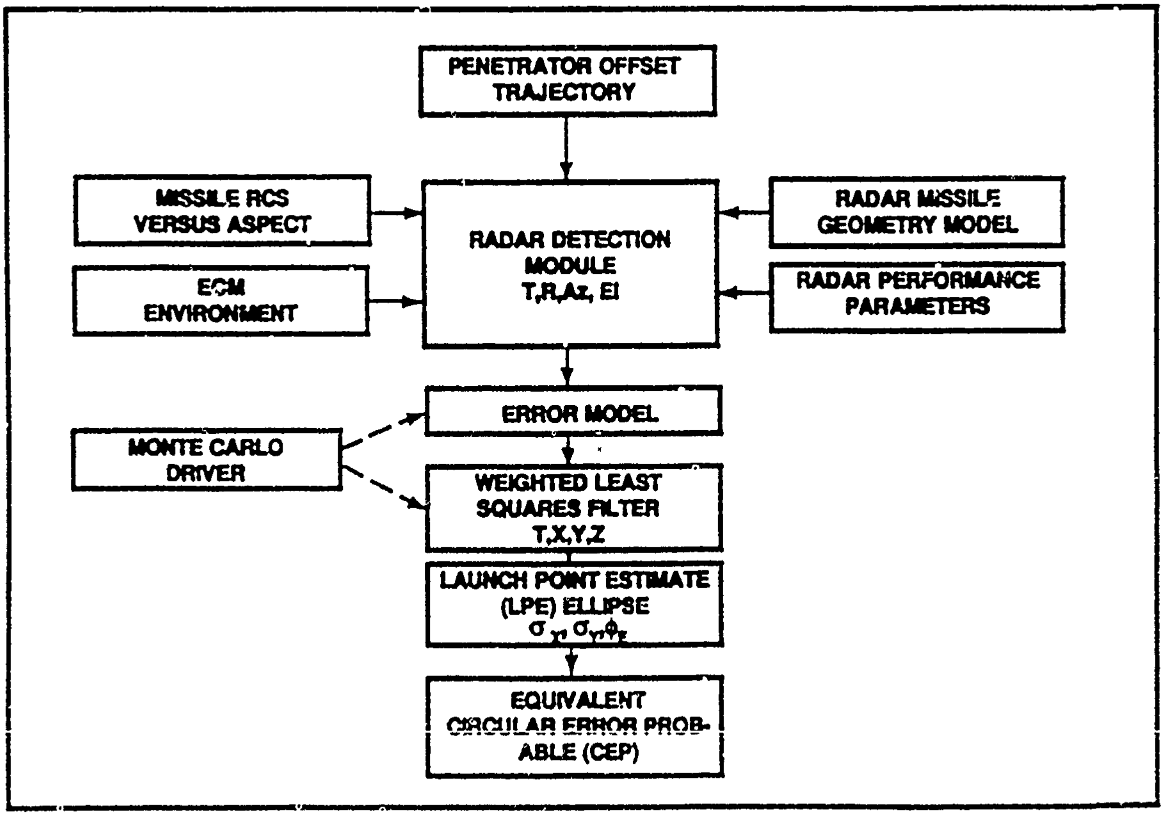

FIGURE 6.0 BACKTRACK MODELING APPROACH

7.4 Backtrack Modeling Approach

Figure 6.0 illustrates the modeling approach for analysing the penetrator backtrack tactic. The threat radar performance parameters will be derived from the penetrator launcher threat assessment. Both current and projected threat counterbattery and battlefield surveillance radar assets will be modeled and analyzed. As shown in the figure, the radar track data can be input to a weighted least squares filter which will be used to compute a launch point estimate (LPE). A primary output of the analysis will be an assessment of LPE accuracy and timeline effects due to: (1) Penetrator offset launch tactic, (2) missile radar cross section, (3) electromagnetic countermeasures (ECM), and (4) radar measurement accuracy. In addition, cued counterbattery weapon system response timelines and penetrator operational timelines will be overlaid to assess the susceptibility of the penetrator to attack from backtrack-derived cueing data.

To assess the need and effectiveness of the penetrator offset launch requirement, the backtracking analysis will also be performed for a non-offset trajectory.

Figure 7.0 and 8.0 are examples of typical outputs of the backtracking analysis. Figure 7.0 shows LPE accuracy for a non-offset trajectory as a function of time-after-penetrator-launch for three separation ranges, (R_p) between the threat radar and the Penetrator launcher. Figure 8.0 shows a typical LPE for an offset trajectory.

8. SURVIVABILITY CRITICAL ISSUES

There are a number of critical technical and operational issues that impact the survivability of the penetrator missile system. This section identifies several specific critical issues, and the associated analysis approach, that will be addressed as an integral part of the penetrator survivability analysis. They are:

- Penetrator Missile Signature and Velocity
- Nuclear Effects
- Terrain Masking and Clutter Effects
- Penetrator Operational Timelines

8.1 PENETRATOR MISSILE SIGNATURE AND VELOCITY

If the penetrator missile possesses a low signature compared to the detection capabilities of the threat, its probability of survival is enhanced. Also, even for a moderate signature, the defense battlespace could be maintained constant (or even reduced) by increasing the velocity of the penetrator missile.

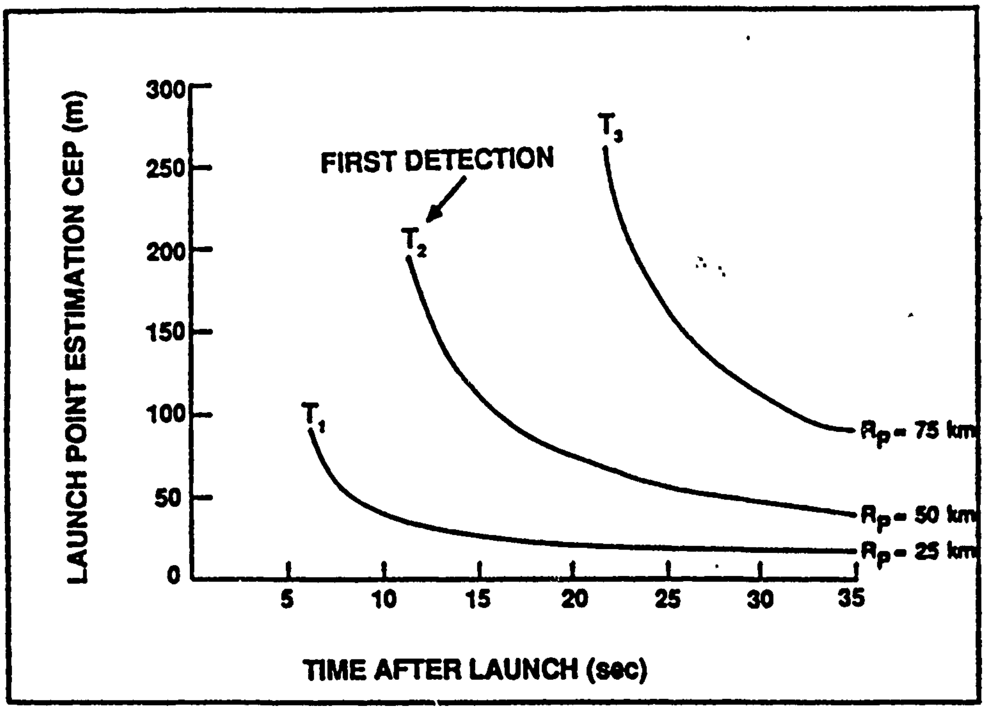

FIGURE 7.0 TYPICAL LPE FOR NON-OFFSET TRAJECTORY

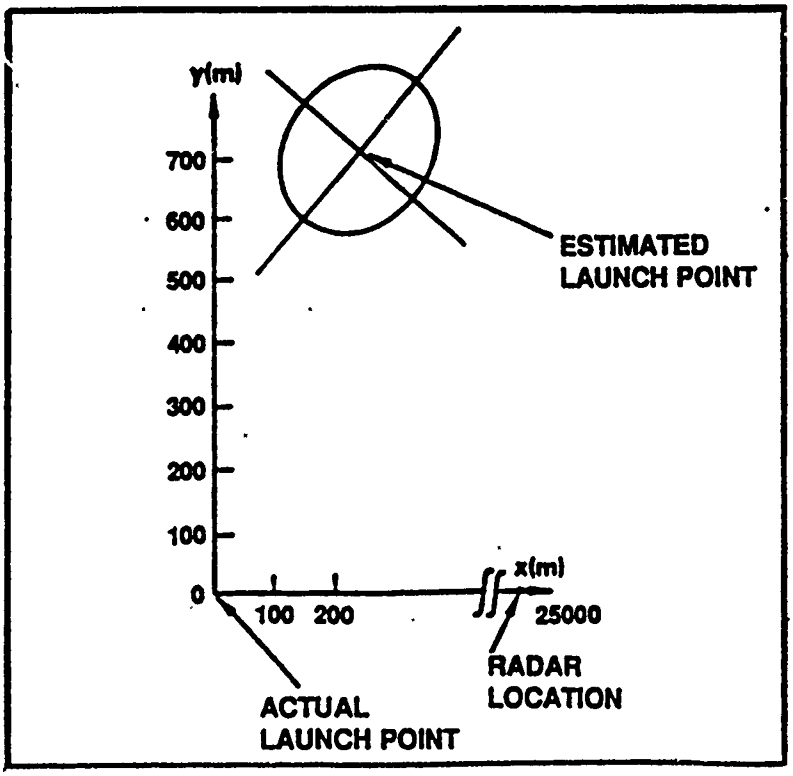

FIGURE 8.0 TYPICAL LPE FOR AN OFFSET TRAJECTORY

8.2 NUCLEAR EFFECTS

Detrimental effects to the penetrator and/or defense system can occur in a nuclear environment. Prompt effects, i.e., weapon-emitted effects which include blast, over pressure, thermal radiation, and electromagnetic pluse (EMP), are the chief cor ·ns.

Another concern is · · sistent effect of nulcear-lofted dust which can last for tens of minutes However, missile hardening techniques, timed spacings between missiles, and appropriate flight lanes can be used to mitigate most nuclear vulnerabilities.

Nuclear detonations may enhance both the survivability and effectiveness of a penetrator. For example, a fireball-induced radar blackout reduces the probability of successful penetrator engagement. Other effects, such as thermal, overpressure. and dust decrease the probability of penetrator interception. The severity of these nuclear effects depend on warhead yield, the number of warhead events and the time and separation distance between events.

Figure 9.0 is typical of the nuclear effects analyzed with many-on-many models. It shows the time-varying level of over pressure, thermal fluence, and wind on a SAM interceptor for two successive nuclear detonations that are time and space separated.

8.3 TERRAIN MASKING AND CLUTTER EFFECTS

For low-flying, reduced-signature tactical missiles, the requirement to accurately model the effects of terrain becomes critical. A low-altitude penetrator may be masked by the terrain at a range much less than the free space detection range of the defense surveillance radar. After a target becomes unmasked, it will usually be in a clutter-free range region for range-gated pulsed radars. This is the area where the target is unmasked but the clutter is still masked. As the target continues to approach the defense radar, the clutter also becomes unmasked and will then compete with the target signal, thereby degrading the detection and track capability of the radar. In particular, the signal returned from the terrain typically limits the sensitivity of the radar receiver, thereby degrading detection and track capability. However, because clutter returns (unlike receiver noise) are often correlated, integration schemes can be used to improve composite signal returns and isolate the target signal.

An additional effect associated with low-altitude flight paths is multipath, which results when the defense radar receives signal returns from the low-flying penetrator along both a direct and indirect path. Signals traveling along the indirect path leave the radar, travel to the penetrator, and are reflected by the Earth's surface before returning to the radar. The constructive and destructive addition of signals traveling along the two paths produces radar tracking errors which degrade intercept accuracy.

8.4 OPERATIONAL TIMELINES

The operational timelines for a "shoot-and-scoot" type of penetrator are critical in determining the weapon systems's susceptibility to the threat

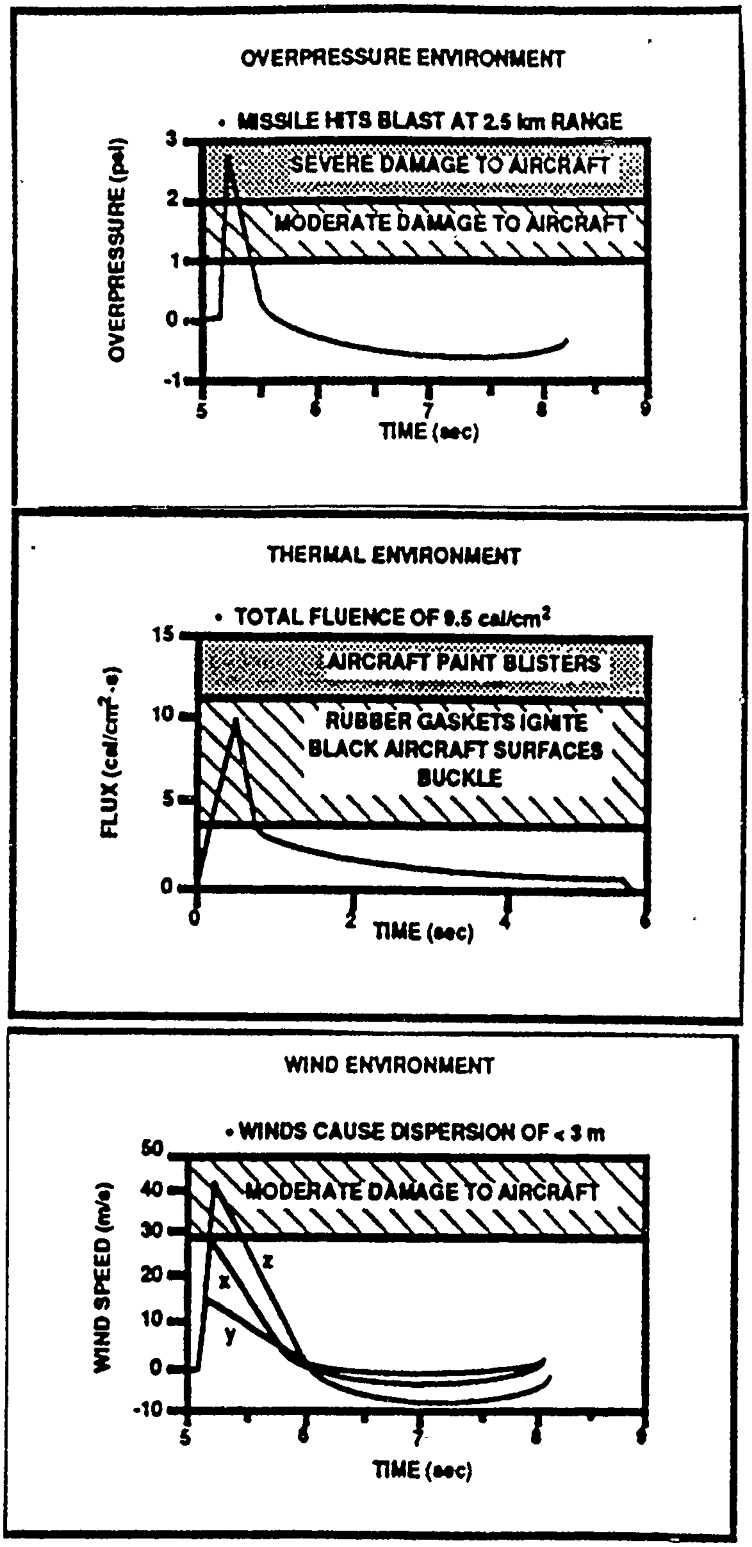

FIGURE 9.0 INTERCEPTOR ENVIRONMENT

counterbattery fire, since these timelines characterize the period in which the launcher is vulnerable to enemy detection and attack.

A typical scenario for the employment of a penetrator is described as follows:

(1) The launcher is in a hide position where it is relatively safe from detection
(2) The crewmen receive a fire mission
(3) The launcher moves from its hide area to a predesignated launch position
(4) At the launch site, the crewmen perform prelaunch operations and launch the penetrator missile (s)
(5) The crewmen prepare to leave the launch site
(6) The launcher moves from the launch site to a reload point and then back to a hide position
(7) The launcher remains in its hide location until another fire mission is received

During steps 3 through 6, the penetrator is exposed and, therefore, is most vulnerable to attack.

Figure 10.0 depicts a hypothetical comparison of a penetrator and counterforce timelines. For the case shown, the penetrator launcher has already departed the launch site before counterfire can be brought to bear; thus, only homing or mass destruction (nuclear) counterforce weapons would be reasonable threats to its launcher.

Analysis of the operational timelines issue will require very accurate data.

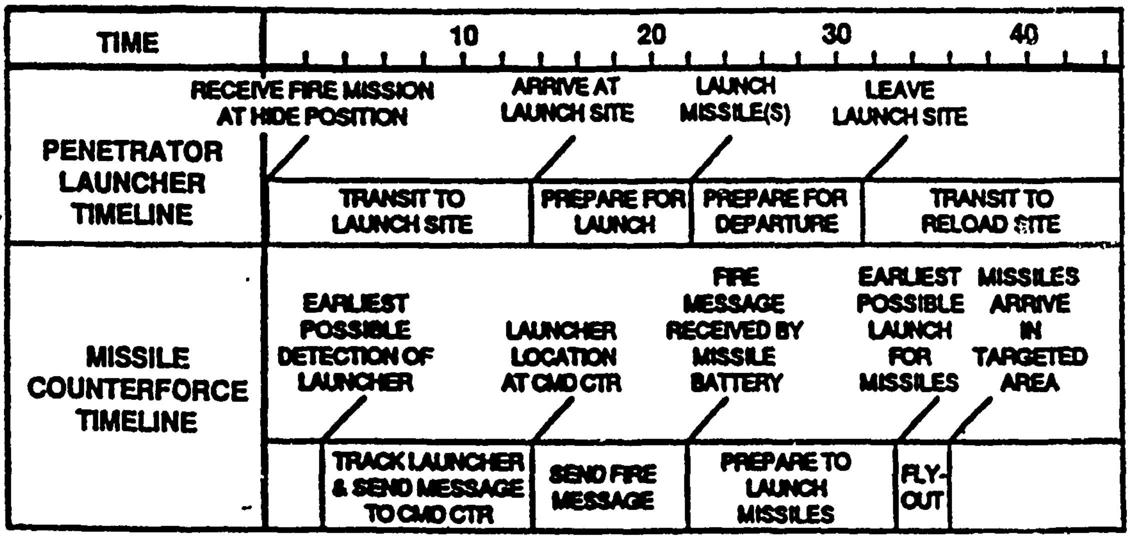

Figure 10.0 Hypothetical Penetrator Launcher/Counterforce Timelines Comparison

8.5 CONCLUSION

Thus, there exists a technical, well-defined methodology for survivability analysis that is in use. This methodology is documentated, for the most part computerized, and has been applied to many systems over the last fifteen years.

#155

TITLE: Manual Evade Model

AUTHOR: Everett C. Reich

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

This paper describes a computer-aided manual methodology for the evaluation of air defense and aircraft mission effectiveness. This methodology provides a total audit trail of in-scenario air defense, and aircraft engagements.

Analysis by USAMSAA in support of the LHX program has, until recently, centered around the use of the Evaluation of Air Defense Effectiveness (EVADE) model. However, the need arose to provide an engagement by engagement audit trail for decision makers, which was not available using the EVADE model. The manual methodology investigates each threat encounter by BLUE aircraft to determine aircraft unmasking, engagement timeliness, and aircrew alternatives during the engagement. These alternatives include maneuvering to remask, returning fire, or continuing the mission as planned. While this methodology is time consuming and labor intensive, the audit trail provides a verification and validation which is not readily available in automated models. In addition, this methodology provides an excellent teaching tool for the would be aircraft survivability analyst. AMSAA is currently developing with the aim of developing an interactive, auditable in-scenario air defense and aircraft mission effectiveness simulation.

#196

TITLE: An Examination of the Effectiveness and Numbers of Light Attack Helicopters Required in the I(BR) Corps in the Year 2000

AUTHOR: Dr. Roger M. Allen

ORGANIZATION: Royal Armament Research & Development Establishment

ABSTRACT:

(1) The study considered ten war scenarios based upon threats to the 1(BR) Corps postulated by Project FORESIGHT in the timeframe of 1998-2008. Assuming that light attack helicopters (LAH) armed with LRTRIGAT could be deployed in anti-armour, anti-helicopter, and air-reconnaissance roles; the study used a mapboard game to assess the number of opportunities for LAH to fly on these missions using current operational tactics to attack RED armour and escort helicopters in areas favourable to BLUE. The number of missions flown was then estimated parametrically for a range of LAH fleet sizes, taking account of practical limitations on LAH availability, including imperfect C3I and losses to enemy fire. These last data were provided by RAE, Farnborough through their HELMIS model, which also provided data on the number of RED vehicles and helicopters killed by each LAH mission.

(2) In this way the study estimated the number of RED targets killed for five selected scenarios, for a range of initial LAH fleet sizes and for various RED helicopter escort policies. Drawing upon an estimate of the number of helicopters likely to be deployable by RED against the 1(BR) Corps in 2001, BLUE's optimum strategy was identified and procurement numbers recommended.

PAPER IS CLASSIFIED
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#157

TITLE: Radar Detection Analysis

AUTHOR: R. Halahan

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

Persistent questions arise in radar detection concerning the sequence of events required for an operator to detect a target on his plan position indicator (PPI). Numerous studies involving BLUE air defense versus RED aircraft and vice versa often start an engagement with radar detection. But the time required for an operator to recognize a target presentation on his PPI has generally been a data gap in the study inputs. Recent agreements between various Army analyst have resulted in a two blip out of three rule of thumb for detection. AMSAA has conducted a study in this area to attempt to fill this data gap. The Army collected a database for FAADS LOS-F-H competition which contains information applicable to this question. AMSAA obtained the database collected for ADATS during these tests from the Air Defense Board. Video tapes of over 600 detection events were examined in detail to determine the blip and scan sequence resulting in an operator detection. Detection was defined for ADATS as first cursor motion to place a target under track. The database supplied by the Air Defense Board also contained numerous identifiers such as to the natural environment, crew makeup, target type, target flight pattern, and ECM environment. The information extracted from the video database was combined with selected detailed identifiers into a LOTUS spreadsheet of over 25,000 elements. The events leading to a detection were sorted by a wide variety of parameters. Each sort was analyzed to determine the statistics of the different detection sequences. The results of these analyses will be presented in the proposed paper.

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#156

TITLE: Army Air Defense Anti-Tank System

AUTHOR: J. Meredith

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

This paper evaluates the reaction times of the ADATS based on data from the Forward Area Air Defense Systems (FAADS) Line-of-Sight, Forward (LOS-F) Non-Developmental Item Candidate Evaluation (NDICE) tests, and the Force Development Test and Experimentation (FDT&E) conducted at White Sands Missile Range (WSMR) in the fall of 1987 and fall of 1988, respectively. Evaluation methodology is presented and algorithms were developed for use in simulations. The evaluation does not include detection times.

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#192

TITLE: Computer Aided Barrier Planning

AUTHOR: Dr. Klaus-Peter Schwierz

ORGANIZATION: DORNIER GmbH
Planungsberatung/Department of Military Consulting
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Federal Republic of Germany

ABSTRACT:

The military branch of the DORNIER Systems Consulting Division is an independent operations research group, working for the German MOD. In general the group performs analyses, mainly based on model calculations; and, thereby, supports the process of decision-finding by the agencies.

Study work on future mine systems is being sponsored by the Armament Department III 5 which is responsible for engineer equipment, and by the; army Staff VI 1 which is responsible for operational analysis. The study work on the future mines is based on operational research methods, starting with the preparation of the engineering analysis of the concepts of future mine systems and ending in a cost effectiveness analysis.

The assessment of how the terrain will influence mine warfare is an important factor in the determination of the effectiveness of mine systems. Against this background the DORNIER Terrain Model was born.

The DORNIER Terrain Model provides a tool for displaying movements of units on battalion level, estimating the requirement of mines by type, quantity, and mix; and for assessing obstacle plans on divisional level and with this the model provides a tool for interactive barrier planning.

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THE SHOCK ACTION OF TANKS

Professor R W Shephard

CORDA Ltd, London

"The morale is to the material as three to one" - Napoleon

INTRODUCTION

1. This paper is written in response to a request to examine the concept of the shock action of tanks, and to define its nature and limits. It starts with some examples from World War I where the effect was first noticed, and traces developments and elaborations to the notion as they occurred subsequently up to the present day.

2. It will be shown that 'shock action' is essentially an effect on the morale of soldiers reducing their will to resist and to fight, but that this effect may also be brought about by means other than tanks. The conditions under which morale effects occur from whatever cause are therefore examined quite generally and the tactical circumstances which influence the likely occurrence of "shock action" discussed. The paper concludes with some thoughts on its importance in a future major conflict in Europe.

HISTORICAL PERSPECTIVES

THE FIRST USES OF THE TANK IN WWI

3. As early as 1916, when the first tanks were under trial and development, thought was already being given to the best tactics to use when they finally arrived on the battlefields of World War I. Lt Col E.D Swinton produced a lengthy treatise on the employment of Tanks (written at that time with a capital T) as a guide to the battle training that was already under way in the so-called 'Elvedon Explosives Area' (Reference 1). Three short quotations from this work are, as will become clear, pertinent to the present paper:-

a) "It is emphasised that the simplest and surest way of destroying entrenched machine-guns is by rolling over the emplacements and crushing them".

b) "Since the chance of success of an attack by Tanks lies almost entirely in its novelty and in the element of surprise, it is obvious that no repetition of it will have the same opportunity of success as the first unexpected effort. It follows, therefore, that these machines <u>should not be used in driblets</u> (for instance as they may be produced), but that the fact of their existence should be kept as secret as possible until the whole are ready to be launched, together with the infantry assault, in one great combined operation".

c) "..... the Tanks will confer the power to force successive comparatively unbattered defensive lines but ...... the more speedy and uninterrupted their advance, the greater the chance of their surviving sufficiently long to do so".

4. The failure to fully comprehend the importance of not committing tanks piecemeal when they were first used (para 3b) is now part of the history of the tank and is well known. Nevertheless, the appearance of the new monster even in penny numbers achieved significant effects on enemy morale by a combination of surprise and the fear caused by a new weapon of unknown capabilities.

5. These effects may be illustrated by the following (somewhat random) extracts taken from accounts written at the time (Reference 2) as records of lessons learnt from tank actions that had taken place:-

a) Tank Action near Hamel, 4 Jul 18 "A feature of the attack was the way in which the tanks manoeuvred to drive right over enemy machine guns, crushing the personnel." (N.B. 60 tanks on a frontage of 6000 yards crushed 26 MGs).

b) Tank Action near Moreul, 23 Jul 18 "The morale effect of fire on the hostile infantry undoubtedly caused many surrenders". "The 6 pr shooting was good and caused many casualties".

c) Tank Action East of Amiens, 8 Aug 18 "The tank came as a great surprise. The morale effect appeared to be 'as great as ever'. The infantry put up no fight. PW all stated that with so many tanks against them it was useless to attempt to fight; that the speed and manoeuvring power of the Mk V tanks and Whippets gave them no chance of defending themselves".

d) Tank Action at Sailly-Laurette, 8 Aug 18 PWs stated that "the sudden appearance of tanks out of mist rendered resistance useless, especially as the infantry followed so closely behind".

6. In commentaries on these early tank actions, there are frequent remarks such as, "the result has been effected by the offensive power of the tank in destroying enemy MGs, etc., but also by its morale effect causing the enemy to surrender when he would otherwise fight", "the fear of tanks is certainly far more widespread than it has ever been", and "a captured German document states that the reasons "(for defeat)" are to be sought in the massed employment of tanks and surprise under the protection of fog". Indeed, according to one PW quoted in these commentaries, "Officers and men in many cases come to consider the approach of tanks a sufficient explanation for not fighting. Their sense of duty is still sufficient to make

them fight against infantry attacks, but, if tanks appear, many feel justified in surrendering". Other similar quotations abound and only one more will be given. In the operation between Ginchy and Delville Wood prior to the Battle of the Somme, one author writes "... the awesome appearance of these strange monsters, emerging from the morning mist that covered the battlefield, was a nerve-shock to the German troops - who at various places bolted when the tanks crawled towards them. The number of such cases showed that a widespread panic might have developed if five hundred tanks had been employed in the first surprise. But on the occasion they were so few that their demoralising effect was too localised to spread". (Reference 3)

7. It was as a result of these and similar experiences during World War I that the concept of the shock action of tanks started to emerge. There was no doubt from the beginning that it was a morale effect - that it caused a diminution in the enemy's will to resist (and the effectiveness of his resistance if he did continue to fight) out of all proportion to the casualties caused. And further, that it occurred because of fear introduced when the new 'awesome' weapon (which was capable of running over a man and crushing him) was first encountered, and especially as he had no ability to retaliate effectively. It underlined the truth of the dictum, "It is of first importance that the soldier, high or low, should not have to encounter in war things which, seen for the first time, set him in terror or perplexity" (Reference 4).

8. Additionally, the sudden appearance of the tanks through the ground mists which were prevalent when attacks took place (generally just before dawn) gave the attack a gratuitous element of surprise which had not necessarily been planned and which made itself felt on soldiers whose tension had been heightened by the noises they had heard of vehicles moving up to the front during the night but which they could not locate precisely.

BETWEEN THE WARS

9. The great tactical problem confronting the armies of the world after World War I was to restore mobility to the battlefield, and the first use of tanks was one portent of future trends. The Allies, however, had tended to use tanks in piecemeal fashion so no new tactical concepts had emerged to really substantiate the use of armour in reinstating manoeuvre as a prime element of tactics. The French in particular, while paying lip service to offensive action, relied on defensive measures; the Maginot line was a dominant element in tactical thinking.

10. The German general staff on the other hand were able to start afresh when Hitler began to rebuild Germany's armed strength (in violation of the Treaty of Verseilles), unburdened with weapons and transport of an earlier generation; they created a new army, designed to harness the tank and the aeroplane, both much improved technically since World War I, into powerful offensive weapons - the Panzer-Stuka team which gave mobility, through shock and speed, and complemented the weight and fire power of the infantry-artillery team. Before giving some examples of the effectiveness of these

developments, it is pertinent to examine briefly some of the roots of the tactical thinking on which they were based.

11. For example, in March 1929 the War Office produced the first official manual an armoured warfare (Reference 5) which embodied the main ideas that had been formulated in theory during the decade since the war, checked by experience gained through field exercises in the two previous years. This manual correctly emphasised the mobility and endurance of armoured formations (".... they might be expected to keep up marches of thirty or fifty miles a day for six days out of seven" - as they did ten years later, fighting on the way!). Another emphatic point was, "The morale and material effect of AFVs on other arms is great. They can, in fact, render immobile, by threat alone, such infantry formations as are unsuitably equipped" - by which presumably was meant 'equipped to retaliate'. More specifically, the manual dwelt on the value of rapid manoeuvre and how it might "confuse the hostile commander and cause uncertainty in his mind; opportunities for producing superiority of force at the decisive place and time will thus be created. This result may be attained by a numerically inferior force which enjoys the advantage of superior mobility". It went on to say, "Victory, however, has not always been obtained solely by direct attack. Superior manoeuvre may in the future, as in the past, cause the surrender of large and important forces when the latter find themselves placed in impossible positions".

12. In spite of criticisms, for example from Lidell Hart (Reference 3), that the publication (which was meant not only for the Army but also to educate public opinion) did not sufficiently emphasise the value of armoured forces for long range strokes against the enemy rear or give enough attention to the importance of low-flying air attack in combination with tanks, there is no doubt that it was a milestone in the development of tank tactics. It contains the seeds from which the German concepts of blitzkrieg blossomed. Regretably, conservative and backward looking influences in the UK spoilt all chances of its main theses being adopted here, and the summer exercises in 1930 did nothing to change "the misuse of armour which was so persistent" (Reference 6). "In this year's exercises, realism was obscured, and the broader issues confused, by misdirection of the 'armoured' strokes"; "... false lessons are drawn because the administrative services, the second-line transport, and the various headquarters assume such puny proportions compared with their war scale"; ".... because they are small in peace exercises they are difficult to strike and their assailants are rarely accorded full and real value for striking them".

13. Nevertheless, helped by the efforts of a handful of enthusiasts, the ideas did not die in this country. Thus in the report of a staff exercise at Cambridge in 1934, held under Lt Col PCS Hobart, the following occurs, "The situations were framed to bring out that the role of the Tank Brigade is to create the maximum amount of paralysis and confusion in the enemy's area; to distract, bewilder, and even paralyse vital headquarters and nerve centres; to interrupt communications and stop the flow of supplies; to cut signal arteries and server control. It is thus attacking enemy morale and organs of control.

It should operate ..... in such a manner as to leave the enemy in doubt as to its actual objective until the last possible moment". The conclusions to the report stress the need to solve the supply problem and, very importantly, the vital necessity of the co-operation of the RAF ("It is not perhaps too much to suggest that bombing attack should form the covering barrage for tank attack" - a statement presaging the battle of Caen in 1944).

14. It is not necessary here to pursue these ideas further, or to detail the arguments which were advanced in UK for and against armoured forces in the years prior to World War II. Suffice it to say that, although the ideas did not die, they were not taken up with anything like the enthusiasm with which they were adopted (and adapted) by generals such as Guderian and Rommel in Germany; it needed us to experience their application against ourselves (but based on our pioneer work) before we were convinced of their soundness. We learnt quickly, however, when the time came.

15. What is important, however, as far as this essay on the shock action of tanks is concerned, is the way in which in the period between the wars emphasis shifted from thinking about the morale effects as being those on front-line soldiers faced with a new weapon and with insufficient anti-tank defence to considering those caused by deep and rapid penetration, attacking from unexpected directions in the rear, and with local superiority of force. To quote Liddell Hart again: "To cut an army's lines of communication is to dislocate its physical organisation. To close its lines of retreat is to dislocate its morale. And to destroy its lines of "intercommunication" - by which order and reports pass - is to dislocate it mentally, by breaking the essential connection between the brain and body of an army" (Reference 7). The new armoured tactics aimed to do all these things.

WORLD WAR II

16. It is not necessary to expound on the success these tactics had on the field of battle in World War II, first for the Germans and later for the Allies. But a few descriptions of actions in which shock action was considered to have had an important effect on the outcome are not inappropriate as illustrations of arguments to be made later.

17. Of the 136 divisions with which the Germans invaded France in 1940, it is hard to believe, in the light of what happened, that only 10 were armoured; used as spearheads, this small fraction decided the issue of the campaign before the mass of the German army came into action (Reference 8) "The Germans had conceived the effective means of creating fire power from a moving base for the support of highly mobile combat elements through close tactical air support. They produced a fire effect so devastating as to dislocate all hostile defenses and permit freedom of movement for a mobile mass. Under this rain of fire from the air, the newer heavy cavalry breached hostile positions by the power of shock. The lighter cavalry ..... rushed forward through the breaches to spread fanlike in devastating attacks upon the nerve and supply centres in the rear" (Reference 9). "The brilliant result of these

panzer thrusts obscured their small scale and also the narrowness of the margin by which they succeeded. That success could easily have been prevented but for the paralysis, and all too frequent morale collapse, of the opposing commanders and troops in the face of the tempo and technique of attack for which their training had not prepared them" (Reference 8).

18. The boot was on the other foot for part of the time in Libya. Thus, in the battle to capture Nibeiwa and the Tummars from the Italians (7 Dec 40), 7RTR led the attack of 4th Indian Division on Nibeiwa camp. After a preliminary skirmish, "two of the leading troops of A squadron drove into the camp and there tackled the enemy artillery and infantry at close quarters spreading confusion and panic. The demoralising effect was increased when B squadron followed up the penetration. The opposing artillery men continued to fire until they were mowed down, but most of the infantry lost heart on seeing that the oncoming tanks (Matildas) were not stopped even by close-range fire". A total of 4000 prisoners was taken. 7RTR only lost seven in killed and wounded. In North Africa, however, it was generally Rommel who, time and time again, was able to achieve success by striking fast, and counting on the morale effect obtained from such a stroke if delivered at the right moment. "By the unexpectedness, speed, and depth of his thrust, he sought to produce spreading confusion and a general collapse" (Reference 3).

19. Another example confirming the effect of these factors in causing a collapse of morale may be culled from Operation 'Astonia' the attack by the Canadian first Army to occupy Le Havre in 1944. General Crocker, as the left wing of the attack, "avoided the obvious line of approach and chose the indirect, the more unexpected". "The attack, carefully mounted, was launched on 10 Sept 44 and within 48 hours Le Havre was completely occupied - whereas the German High Command had imagined that the fortress could hold out for months". "..... 11,300 prisoners were bagged at the cost of less than 500 British casualties. The defenders' morale had been damped by the accelerating onrush of the Allied armies towards Germany and the feeling of isolation, as well as being softened by mass artillery and air bombardment" (Reference 3).

20. One final observation needs to be made. Subsequent to the above attack, 4RTR were engaged in mopping-up operations near St Pierre-sure-Dives. When they drove into the town they found it deserted; the enemy had gone during the night, "apparently shaken by a report that 150 tanks was about to assail him" (Reference 3). The real number was 25. This tendency to grossly exaggerate the strength of the attacking force often occurs in similar circumstances - for example, at Arras in 1940 when an attack by 72 British tanks was thought by the Germans to be an assault from five divisions (Reference 10).

POST WORLD WAR II

21. The successes achieved by using the firepower, protection and mobility of armour to achieve shock action in World War II have ensured that the

importance of employing tanks in this way has permeated Royal Armoured Corps training ever since. For example, in 1965, a training pamphlet (Reference 11) states "The main roles of the RAC are:-

a) Aggressive mobile action to destroy enemy armoured vehicles and give support to infantry.

b) The exploitation of shock action on the battlefield.

c) Reconnaissance."

It continues, "Used boldly in concentration with all four characteristics" (firepower, protection, mobility, and flexibility)" fully exploited, tanks can produce a shock effect on the enemy. This is caused by:

a) Surprise, with the consequent effect on enemy morale and reactions.

b) The concentrated fire of tanks

c) Numbers of tanks penetrating the enemy area, particularly from the flank or rear. The overwhelming number of moving shooting tanks prevents the enemy from firing his weapons effectively. Exploitation of this effect into deep penetrations may cause the enemy to collapse"

These ideas are further elaborated: "The ability of tanks in concentration to produce shock action must be used whenever possible. Unless the momentum of the penetration or assault can be broken by the enemy, his forces will be disorganised or defeated. Surprise must be exploited if full value is to be obtained from this important effect of tanks. Speed of movement, ground, and the cover of darkness or bad visibility must be used to produce surprise. APC borne infantry and artillery help to maintain momentum in the assault and exploitation, and support tanks in producing shock action".

22. A current training pamphlet (Reference 10) has much the same theme. "The men .... who ended the stalemate of trench warfare in World War I had .... an understanding of the paralysing effect that a boldly led force, attacking from an unexpected direction, can have on an enemy. The purpose of today's Main Battle Tank is to produce just this quality of shock action ...." It defines shock action as "the combined effect of surprise and firepower. By attacking in strength at a weak spot, at an unexpected moment and from an unexpected direction, an armoured force can destroy large numbers of the enemy and, more importantly, seize the initiative from him. Other arms can contribute to shock action, but it is the primary role of armour and is common to all phases of war". On surprise it says, "Surprise multiplies the physical effects of an action many times." "The elements of surprise are: originality, audacity, speed, deception, secrecy, and concealment". "It keeps the enemy off balance".

23. A short survey (Reference 12) of a number of writings on Soviet tactical theory (References 13-18) indicates that, presumably as a result of experiences in World War II, the Soviets are well aware of the concept of shock action but, like many writers on this side the Iron Curtain, refrain from defining it too specifically. Key words used by their planners are 'tempo' and 'surprise'. They will seek to overcome NATO forces so rapidly so that there will be no time to form a coherent defence. By surprise, however, they do not necessarily mean the same as Western military thinkers. "They make a clear distinction between the concepts of 'being taken unawares' and 'lacking sufficient time to take precautions'. It is the latter that the Soviets consider to constitute surprise. A military commander who was expecting the attack but nevertheless had insufficient warning time to make adequate preparation is considered to have been 'surprised'". This emphasis on tempo and surprise "implies that a shocked defender will be unable to assimilate information on what is happening fast enough to be able to make decisions and communicate them in time to deal with the Soviet attack". Paralysis of the mind of the commander is the objective.

COMMENT

24. It is believed that sufficient has been written by now to give the reader a clear indication of what is generally meant by the shock action of tanks, and the way in which thinking about it has progressed since the tank first appeared on the battlefield. Discounting early episodes in World War I, in which a considerable amount of the fear felt by the German soldiers was undoubtedly due to the fact that they were encountering tanks for the first time - the primeval fear of the unknown - there is considerable evidence that conditions in which a feeling of helplessness and hopelessness due to the overwhelming (but possibly only local) superiority of the attack is created, and in which men know they have no reasonable chance of relaliation can cause a breakdown in the will to resist and lead to wholesale surrender. These and other features that are important in the reduction of morale will be elaborated upon in the next section.

25. Before doing this, however, there is a very important point which seems to have emerged from the above discussion that needs elaboration. The great contribution made by tacticians between the Wars - Liddell Hart in particular - was that they were able to translate the concept of shock action as it had appeared in World War I to the anticipated battlefields of the future, in which operations would be dynamic and manoeuvre a key attribute. As one writer puts it, they were able "to replace the concepts of mass per se by, to use a mechanical analogy, moment and momentum" (Reference 9).

26. But having said this, and not wishing to denigrate in anyway the advances to tactical thinking they were able to make, it must nevertheless be noted that their ideas were not really new. Throughout history it has always been accepted (Reference 20) that there are three basic ways of overcoming an opponent: by superior force; by attacking him at a weak or vulnerable point; or by demoralising or disorganising him by surprise (an attack aimed at the

mind and morale). Alexander the Great, and Hannibal in particular, were among the earliest generals to appreciate the role of the cavalry in achieving the last of these objectives; cavalry consequently came to be regarded as the decisive arm. Even after periods of decline - such as occurred for example when the invention of gunpowder provided the infantry with the ability to defeat the heaviest armour that could be carried by the horse cavalry - a revision of tactics allowed the mobility of the cavalry to be restored by making use of firepower from the infantry and artillery to support them. Marlborough, for example, used cavalry in mass at the Battle of Blenheim (1704) to achieve shock. Similarly, under Frederick the Great, the cavalry won at least 15 out of 22 battles by working in close cooperation with gun and musket (Reference 9).

27. The cavalry charge on horses was essentially doomed in the mid-1800s, however, by the invention of the cylindro-conoidal bullet which gave the infantry an effective range of 1000 yards. From then on, no cavalry actions of any significance occurred. Either the cavalry were used primarily for reconnaissance (as in the American Civil War) or fought dismounted (as 'dragoons' in the Boer War, for example). In World War I, "the limitations which the bullet placed on cavalry movement begot the trench; for if the cavalry had been able to move, the construction of entrenched fronts would have been all but impossible" (Reference 9).

28. By restoring the ability to manoeuvre on to the battlefield and thus taking over this role from the horse cavalry, the tank allowed the concept of achieving tactical aims by the uses of shock action to become once again a practical operation of war. It so happened that by World War II the tank had progressed technologically to a weapon with all the right attributes to achieve shock effects - indeed, was at that time the only weapon able to do so - and it is for this reason that we give emphasis to this role of armour today. But it must be emphasised that the concept of shock effect is <u>not</u> one that is peculiar to tanks only. It is also able to be brought about by other mobile weapons as history shows.

29. Before the implications of this statement for the future can be examined therefore, it seems necessary to examine briefly the general nature of morale effects on the battlefield and the circumstances in which they are most likely to occur.

A DISCUSSION ON MORALE EFFECTS

PREAMBLE

30. Clauswitz once stated that the effect of battle "is more a killing of the enemy's courage than of the enemy's soldiers" (Reference 4). This statement has been extended: "The major stress that can evade and destroy a man's courage and lead to mental breakdown is fear" (Reference 21). But fear is not the only contribution to a deterioration of morale. A survivor of the defence of Calais (May 40) stated, "The breakdown of normal organisation and break-up

of previously cohesive groups upset the men and had an adverse effect on morale" (Reference 22).

31. Other commentators stress the adverse effects of cold, of noise, of lack of sleep and fatigue, of hunger and thirst, of disease and isolation in lowering the will to fight and helping bring about a collapse of morale. But although these factors undoubtedly contribute (as do others to be discussed) to the likelihood of morale effects taking place, by themselves they will rarely cause breakdown among disciplined troops. Fear is without doubt the key that opens the door to the occurrence of morale effects.

32. The greatest fund of original writings on the morale effects of weapons is to be found among the studies carried out during World War II when the morale effects of artillery bombardment came under scrutiny prior to the D-day landings (References 23-25). These led to some "rules of thumb" being developed which gave the intensities of bombardment (in lb per sq yd per hour) needed to cause "neutralization" and "demoralization" of troops at the target - the former being defined essentially as a morale effect (causing diminition in performance) which lasted only while the bombardment was taking place; the latter, as an effect which continued after the bombardment ceased and led the inability to offer effective resistance - as at Pantellaria.

33. Fortunately for the present essay, these studies did not confine themselves entirely to artillery bombardment but looked at the generation of morale effects in general and for different weapons. A precis of some of their findings which are pertinent to the present essay will now be given.

THE CAUSES OF MORALE EFFECTS

34. There is no morale effect without lethality - but the morale effect is not solely dependent on lethality. "There is historical evidence which indicates that periods of temporary loss of morale or efficiency may follow the sudden disruption and shock resulting from the infliction of even a moderate number of casualties in a short period" (Reference 26).

35. Morale effects may take the form of any or all of the following:-

a) Direct and more-or-less rational fear of death or injury. In particular, loss of morale will occur if a soldier feels he is under "personal attack" by the weapon. (This is probably the main difference between being attacked by a tank and a projectile. The latter is somewhat "random". The former gives a feeling of being directed by a selective intelligence against him).

b) Instinctive fear arising from the sub-conscious mind, often not obviously connected with the fear of death. (The tank may evoke the ancient racial experience of being hunted by dangerous animals, in the same way as the flame-thrower evokes the primitive fear of fire).

c) Fear of the social consequences of showing fright; that is of being thought a coward. (And hence, conversely, the more likely that morale effects will occur when men are isclated and cut-off (Reference 21)).

d) A conviction, reasonable or unreasonable, of inferiority, helplessness and hopelessness; that is, of being overwhelmed. (In general a soldier will judge the enemy's strength by the strength employed against him locally. Tanks appearing unexpectedly can easily give him the impression not only that there is overwhelming force being brought to bear against him (especially if his anti-tank weapons are ineffective) but also that this condition prevails all along the front - he will not know the true general position).

36. Against this background, it is possible to list some of the factors which have the biggest effect on the morale effect of a weapon:-

a) Its real lethality.

b) Its believed lethality - consider the reputation of the German 88mm, for instance.

c) The nature of the casualties it causes - the higher the ratio killed/wounded, the greater will be the effect on morale.

d) The capacity not only to kill but to annihilate, or kill in a particularly brutal fashion - such as being crushed or blown to smithereens.

e) The volume in which it is employed - a weapon employed in penny numbers can be resisted; if employed in concentrations it destroys all rational hope of success against it.

f) The degree of surprise involved - the unexpectedness of the attack.

g) The degree of suspense involved - sounds, for example, of tanks whose approach is difficult to judge.

h) The direction of attack - attacks from the rear or from above (eg by the dive-bomber) are particularly disliked.

i) The extent to which an appearance of an aimed personal attack directed by an intelligence, and not at random, can be achieved.

37. One final general comment can be made. The more active the role in which the soldier is engaged, the more reasonable and logical will be the nature of any morale effect upon him. In attack and in active defence, the fear of a weapon is closely related to its real lethality. It is in passive defence and in waiting to attack that attacks on the irrational aspects of morale have then the best chance.

MORALE EFFECTS OF TANKS

38. Some reflection on the ideas propounded in the last three paragraphs will soon suggest the reason why tanks are weapons which, correctly used, have gained an impressive reputation of being capable of causing serious breakdown in enemy morale:

a) their direct firepower against unprotected infantrymen. especially at close quarters, can be overwhelming (para 35d); it will tend to kill rather than wound (para 36c), and will be aimed rather than random (para 35a);

b) their mobility enables them to achieve surprise (para 36f), to attack from the flank or the rear (para 36k), and to concentrate so as to give overwhelming local superiority (para 35d and 36e);

c) their armour has often (certainly in the early years of World War II) meant that they were invulnerable to infantry anti-tank weapons, adding to a feeling of helplessness against them (para 35d).

d) their flexibility allows blows to be struck in quick succession in unexpected places at unexpected times and from unexpected directions creating surprise and numbing the mind of the enemy commander - paralysing the organisation and not just the individuals in it (para 15 and Reference 27).

39. The extent to which a commander is able to devise tactics which enable him to exploit as many as possible of these characteristics simultaneously against the enemy will decide the extent to which effects on morale are produced and shock action said to happen. One important caveat is necessary however. If full value is to be gained from any breakdown in morale that occurs, it is essential that mobile infantry are available to exploit the situation without delay - otherwise there is a possibility (indeed a probability) that the enemy will recover from what may be only a temporary psychological upset (Reference 28). Armour should not as a rule be thought of as "going off on independent missions by itself" (Reference 20) but as forming the spearhead of mechanised teams of all arms, offensively minded yet capable of holding a firm base from which to mount operations.

SHOCK ACTION IN THE FUTURE

40. It would be unreasonable to suggest that shock action is likely to diminish in importance in the tactical thinking for armour for the future. Combining surprise with massive firepower in an area (particularly in the enemy's rear) will continue to have an effect out of all proportion to the size of force involved.

41. However, one major fact has changed since World War II which is likely to affect the extent to which tanks can achieve shock action; namely, the

very great improvement in anti-tank capability which now exists and the anticipated increases in it in the future. In particular, with an increased anti-tank role becoming available to the artillery as SMART munitions are improved the firepower which can be brought to bear against a tank thrust is considerable.

42. It will have been noted that a feeling of being overwhelmed and with insufficient means of retaliation has been common to many of the historical actions described where shock effects have taken place. The question that arises is whether, with the level of anti-tank defence likely to be available in the future, this feeling of inability to retaliate will continue to be so important; if the soldier has confidence that he can defeat the attacking tanks with the weapons he has with him or in support, will he not be less likely to give in?

43. Any answer to this question must be conjectural. Nevertheless, there would seem to be some grounds for expecting that, because of the improvement in anti-tank defence envisaged for the future, the shock action of armour is likely to be less important than it has been. If World War II tactical concepts continue to be employed unchanged one unknown quantity would seem to be the extent to which armed helicopters used in conjunction with tanks might be able to redress the balance by increasing surprise (through speed of manoeuvre), by attacking from unexpected directions (especially from the rear in conjunction, say, with a flank attack by armour), and by bringing fire (or even flame) down on the opposition from above - an especially unnerving form of attack. The use of helicopters with tanks to restore their efficiency in causing shock would seem to warrant further study; it is in accord with experience in World War II of the value of combining air attack with land attack in offensive operations.

SUMMARY

44. This paper has examined the concept of shock action from the time tanks were first used in WWI to the present day.

45. It has shown that shock action is the name given to a tactic which, generally by means of manoeuvre, brings overwhelming superiority of firepower to bear unexpectedly in terms of time, place, and/or direction - albeit only locally - and so produces an effect of helplessness and hopelessness on the enemy, lowering his morale and inducing paralysis in command. The effect is aggravated if he considers he has no reasonable chance of retaliation and if, for instance, dislocation of lines of communication and lines of retreat lead to a feeling of isolation.

46. Shock action may take place in all phases of war but is likely to be most effective against troops engaged in roles which do not require much activity (e.g. passive defence or waiting to attack) or against troops who are tired and hungry.

47. Some factors which are particularly important in achieving a morale effect of this type include

a) Using weapons with high lethality, real or believed, in concentrations and not piecemeal.

b) Achieving surprise in time, place, and direction of attack.

c) Using weapons which employ aimed fire, give a high ratio of killed/wounded, and/or kill in a particularly brutal fashion (e.g. crushing).

The tank is shown to be a weapon which, correctly used, can exploit all these characteristics extremely advantageously, but is not the only weapon that can produce shock effects.

ACKNOWLEDGEMENTS

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EVALUATION OF DESIGN AND COMBAT VALUE OF THE ANTITANK WS
PANTHER BY COMBAT SIMULATIONS (ELEVATED WEAPONS PLATFORM)

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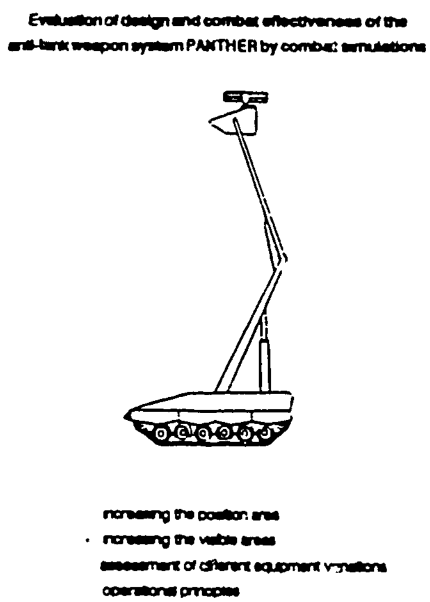
1. Introduction

The future threat to the combat troops on the battlefield is fundamentally determined by the wide range of armoured weapon systems which are supported by attack helicopters.

This threat is to be countered in the German Army by, amongst other weapons, the antitank and antihelicopter armoured vehicle with elevating platform, in short named the PANTHER tank destroyer.



An overview is given in this briefing as to how estimates of both the combat effectiveness of the weapon system (in combined arms combat at the battalion/regiment level) and of the system configuration (sensors, armament) were achieved, using a combat simulation model (PABST) or submodules from it. In particular, attention is paid to
- Increasing the PANTHER's position area
- Increasing the visible areas
- Assessment of differing equipment variations
- Operational principles.

2. Advantage of an Elevation of the Armed Platform

Where does the advantage of an elevation lie?
And why is an elevation necessary for long-range antitank and anti-helicopter defence?

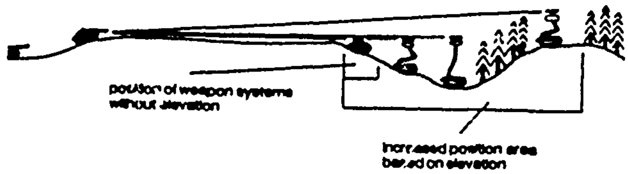
In Central Europe, a great deal of the ground over consists of bushes, trees, woods, buildings and many other objects. In conjunction with a mostly hilly terrain, this leads to many disruptions of visibility of an approaching attacker for the ground-based vehicle.

Therefore, basically, only a comparatively small number of good fighting positions emerge for long range (more than 2 km) antitank defence in prepared defence terrain.

2.1 Position Area

The elevation of an armed platform to over 10 m in heigth can provide remedy. With it, a larger position area can be obtained. The term 'position area' means here the area from which it is possible for a weapon system to get a view of a particular target area.

Example of increasing the position areas

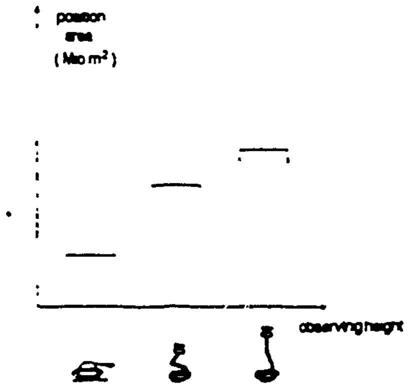


If evaluations of investigations of scenarios from standard situations in Northern and Southern Germany terrain are considered, the increasing parameters of the position area can be discerned with ever-increasing elevation.

The viewgraph shows the possible position area from which fixed attacker courses at distances of 2 - 5 kilometers are visible, depending on the elevation height.

Average value of position area
depending on elevation height

(positions with view to attacker courses in distances from 2 - 5 km)

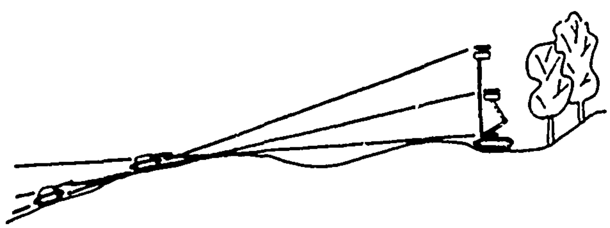


What is shown here is that, with an elevation of more than 10 meters, three times more position area is available than for a conventional weapon system such as missile tank destroyer.

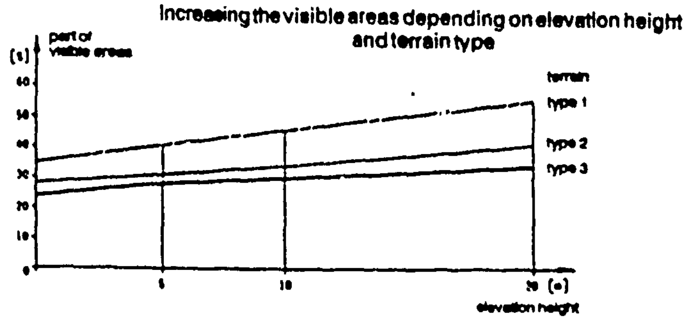
2.2 Visibility

The second advantage of elevation is greater visibility from a previously determined position of a target area.

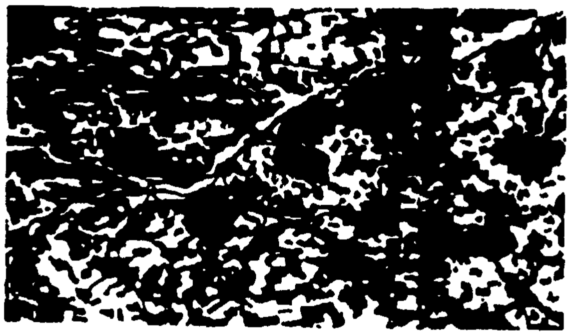
Example for visibility into target area
depending on elevation height



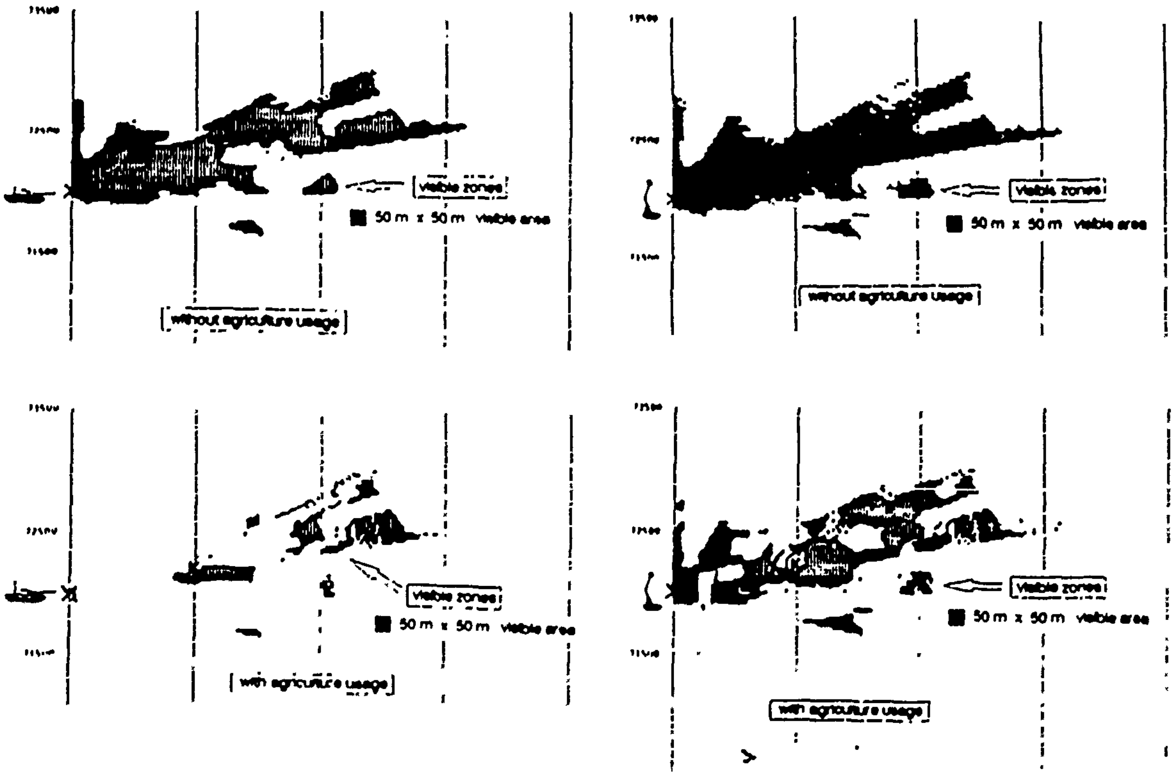
What counts here is the visible area of the target area. If we consider the result by comparing the elevation heights, only a small advantage is gained from increasing elevation.



This, however, only applies if the agricultural use of the terrain is ignored. If the full height of maize or wheat fields is taken into consideration, then the result is a completely different picture. For this it is necessary to take account of the agricultural use of the terrain in the digitalized terrain in the computer program. The next viewgraph shows an example of such types of vegetation.



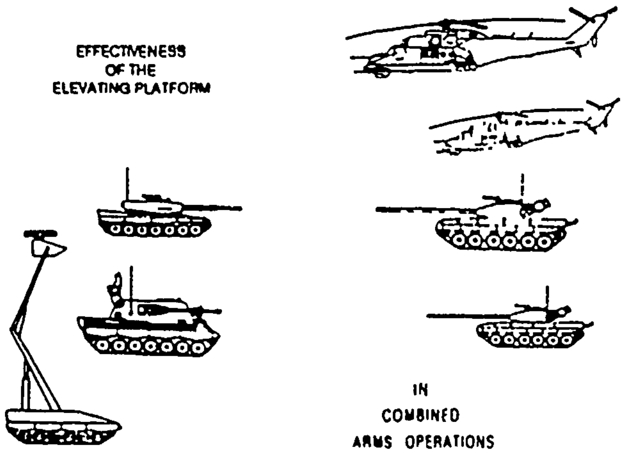
If one considers the visibility from a carefully selected tank position for an observer (= elevated height) of 1 m 80 (not quite 6 feet), for example for MBT, and at 12 meters (for an elevated platform), there are only slight differencies noticeable (see shaded areas), if the agricultural land usage is not taken into consideration.



If these fields are similarly taken into account, important differences in the favour of the elevating platform are the result.

These, and other, considerations led to the development of the PANTHER tank destroyer.

3. Effectiveness of the Elevating Platform in Combined Arms Combat



3.1 Overview

Out of the considerations affecting elevating height and the necessary equipment, such as armament and sensors, a weapon system was created which, in a particular mode and structure, was be deployed in combined arms combat, subject specific employment doctrines. The task of the combat simulation was to generate in standard scenarios

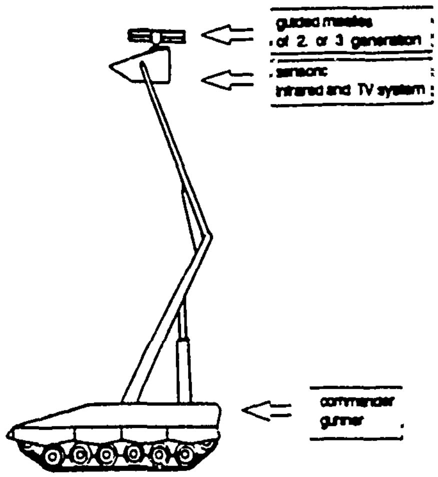
- an assessment of the combat effectiveness of the tank destroyer and to show, what changes or advantages and disadvantages resulted from
  - guided missile alternatives of the 2nd and 3rd generations
  - differing sensor equipment and
  - variation of the operational profiles

  for the tank destroyer.

3.2 Deployment of the PANTHER tank destroyer in Combined Arms Combat

The tank destroyer is equipped with an elevating platform on which the sensors for target acquisition and the guided missiles for target engagement are installed. The combat activities are undertaken by 2 men from a combat compartment in the vehicle.

Tank destroyer PANTHER



two tasks
- long range anti-tank defence
- anti-helicopter defence

The tank destroyer has to fulfil two tasks on the battlefield:
- long range antitank defence with guided missiles of the 2nd and 3rd generations
- antihelicopter defence either with special missiles such as STINGER or with antitank missiles of the 3rd generation.

In battle it can only fulfil one of these tasks as its main task. The other task is undertaken in self-defence. The following structure to be assessed was obtained from further considerations which were supported by studies.

EMPLOYED FORCES DEFENDER		EMPLOYED FORCES ATTACKER	
MBT	LEOPARD 2	MBT	FST
MICV	MARDER 2	MICV	BMP Fo
ATCV	PANTHER	CH	HIND E/HAVOC
ARTILLERY		ARTILLERY	
ENGINEERS			
(50 weapon systems)		(200 weapon systems)	

Numbers of ATCV PANTHER per Bn	
anti tank defence	2 platoons with 6 weapon systems
anti helicopter defence	1 platoon with 3 weapon systems

In the defending tank battalion

2 platoons of PANTHER tank destroyers (6 weapon systems) were deployed for antitank defence and

1 platoon of PANTHER tank destroyers (3 weapon systems) for antihelicopter defence.

For the defender, in the military scenario, the tank battalion with about 50 weapon systems must be simulated with

LEOPARD 2 MBT's
MARDER 2 APC's
PANTHER tank destroyers
Artillery
Engineers (obstacles).

For the attacker, the simulation has a tank regiment with about 200 weapon systems

FST MBT's
PBMP APC's
HIND/HAVOC AT's
Artillery.

These weapon systems must be deployed over typical central European terrain. The terrain area HERZOGENAURACH, located in the Southern part of Germany, was selected and digitalized for this purpose.

3.3 PABST Computer Model

The computer model must therefore simulate
- terrain
- weapon systems and
- movement behaviour (scenario).

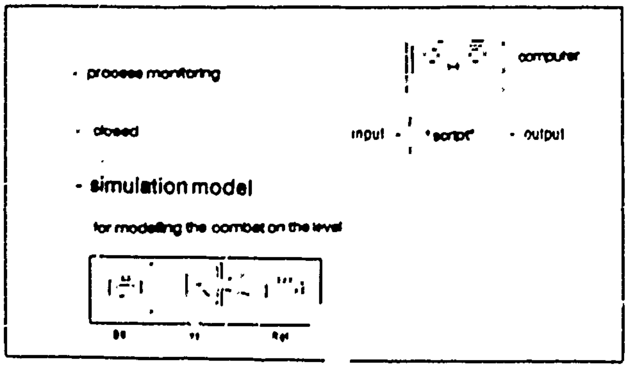
P A B S T

(Anti-tank Defender Evaluation Instrument)

Event sequence - combat simulation model

The PABST combat simulation model was used for this. The name PABST stands for PzAbwehrBewertungsinstrument (antitank defence assessment instrument). It is a high resolution combat simulation model which can simulate in detail all activities of weapon systems on the basis of event sequence. It is a closed model, i.e. all tactical decisions must be included in advance.

PABST ?



3.4 Weapon Systems Data

In order to be able to answer questions on changes in effectiveness depending on armamentand sensors, the individual components of the weapon system must of course be simulated in detail.

For the tank destroyer therefore
- the guided missile was considered for
    - time/distance behaviour
    - trajectory
    - hit description
    - destruction effect
    - reliability,
- the sensors for
    - TV optical means
    - far-looking infrared
    - display systems

separately for the commander and gunner.

This degree of detail in the simulation must, of course, be observed for all other weapon systems participating in the battle.

3.5 Results of the evaluation

As already listed in 3.1, comments to the following questions should be given:

Effectiveness of weapon system PANTHER
in combined arms combat

- contribution of weapon system PANTHER on the success of combined arms battle
- effectiveness of weapon system PANTHER against tanks and helicopters
- variation of armament and sensors
- operational profiles

a) What contribution can tank destroyers with elevating platforms make to the defender's successful combined arms combat?
b) What level of effectiveness do tank destroyers have against tanks and helicopters?
c) How does the combat effectiveness alter, given variations in
   - armament and
   - sensors?
d) In which defence areas, out of which the tank destroyer is engaged, does it achieve its greatest successes and suffer its greatest losses?

The basis for the answers to these questions is the battlefield in 2000. As a first step, armament with fire and forget guided missiles (3rd generation) and good sensor equipment for reconnaissance and engagement were taken into consideration.

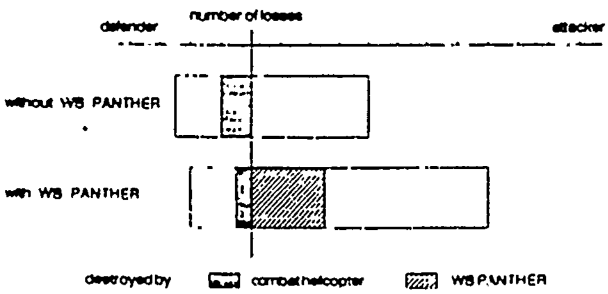
Contribution of the Tank Destroyers to the Success of Combined Arms

To be able to determine the tank destroyer's contribution to the overall combat, a battle was played first in which the defender fought without tank destroyers. In the second step, the tank destroyer as then deployed. The following viewgraph shows the number of successes and losses per battle for the defender.

On the left is the result for the defender losses and on the right the defender success, the attacker losses.

Contribution of WS PANTHER to the success of combined arms

Total losses as a function of the weapon system mix of the defender

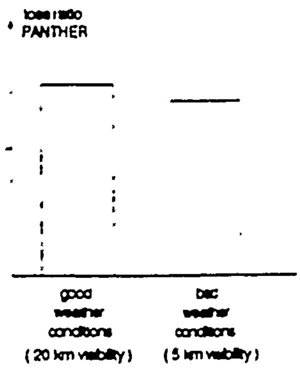


From the length of the bar and the proportion of tank destroyers, it can be seen that the deployment of the PANTHER tank destroyer gives the defender great effectiveness, and the lower effectiveness of the enemy combat helicopters.

Combat Effectiveness of the PANTHER Tank Destroyer

The combat effectiveness can best be seen using the tank destroyer loss ratio, i.e. tank destroyer hits divided by losses of tank destroyers. The viewgraph shows the loss ratio for good visibility (20 kms) and for poor visibility (5 kms).

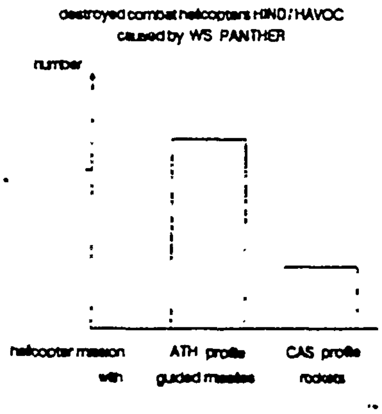
Combat effectiveness of WS PANTHER
(loss ratio)



The comparatively high loss ratio of more than 10 shows that up to about 14 attackers are destroyed by the tank destroyer until one tank destroyer is killed. On the basis of the small visible target area of the weapon, the tank destroyer has considerable advantages in the direct firing weapons combat and is only endangered by artillery and tanks at short range. Detection of this small target area is scarcely possible at a range over of 2 kms and this has been confirmed by field trials. For antihelicopter defence, however, only these attack helicopters can be engaged which attack from steady flight or hover. Attack helicopters in CAS can only be engaged to a small extent due to their short exposure time.

Combat effectiveness of WS PANTHER

(success against helicopters)



Alteration of Combat Effectiveness given:

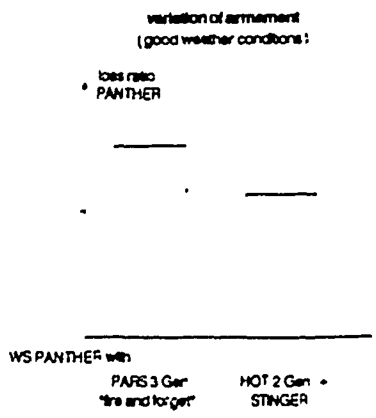
A Variation of Armament

The tank destroyer is to be deployed around the year 2000. Whether then a 'fire and forget' missile will be available is uncertain. An important question was thus how effective is the tank destroyer with 2nd generation guided missiles such as HOT and with STINGER.

The next viewgraph shows, on the left, the loss ratio for the tank destroyer with 3rd generation guided missiles and, on the right, that for the tank destroyer equipped with 2nd generation guided missiles. In this case the loss ratio decreases to about 10. That means, the tank destroyer is still effective in this instance.

Combat effectiveness of WS PANTHER

(loss ratio)

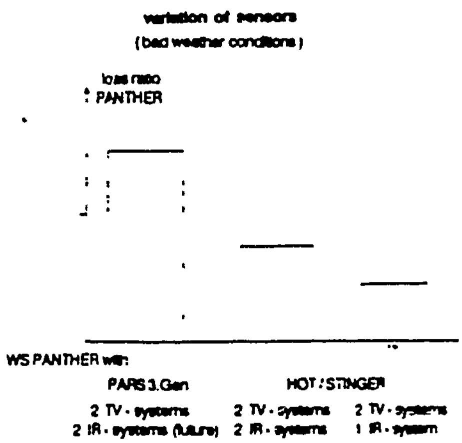


Sensoric Variations

In the next step, the question was asked, as to how far the costs for the whole system could be reduced by saving optical displays without considerably reducing the combat efficiency of the weapon system.

Commander and gunner sit in the vehicle and, originally, both had far looking infrared and TV systems. This is necessary as good sensors must be available for for the elevation of optical means and weaponry as no direct sight is possible with the human eye. The investigations for this were conducted under poor visibility conditions. Savings here should affect commanders who then only have TV systems.

Combat effectiveness of WS PANTHER
(loss ratio)

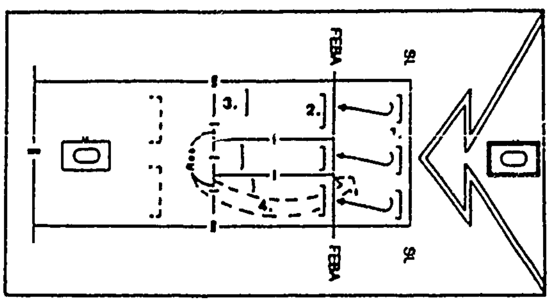


With this saving, as shown by viewgraph, the combat effectiveness of the tank destroyer is reduced by about 65 %, starting from the original equipment with 3rd generation missiles. A saving in this area thus considerably reduces the effectiveness of the whole system.

Effectiveness of the Tank Destroyer in the Various Defence Areas

The tank destroyer should of course be deployed in all phases of a defensive battle such as
- battle of the security line
- battle from FEBA positions
- battle from rear area positions
- support of counter-attack from positions near MBT positions.

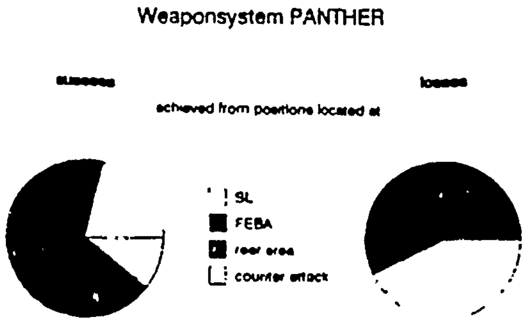
WS PANTHER positions within the defence area



1 security line
2 FEBA
3 rear area
4 counter attack

The tank destroyer is variously effective and threatened from different areas. In the combat simulation, what was revealed was how great this effectiveness and this threat are for the deployment of the tank destroyer.

In the viewgraph the tank destroyer's successes are listed on the left-hand side, with reference to the respective area, from which they came. On the right-hand side, the losses are treated in the same way.



The greatest successes of the tank destroyer are achieved from the rear area position, the least successes are noted in support of the counter-attack.

But the most tank destroyer losses were suffered in the counter-attack.

One of the recommendations for the doctrine of deployment was therefore not to deploy the tank destroyer in the counter-attack phase.

4. Summary

A large number of investigations and assessment were carried out. There is not enough time available here to present them all.

However, what could be seen in all these activities was that the introduction of an elevating with sensors and weapons as the PANTHER tank destroyer with 3rd generation guided missiles meant a considerable increase in effectiveness for the defender. However, this only applied when the system was well equipped with optical means. The advantage of this weapon system over conventional tanks lies in its good passive protection due to the small target area of the elevated weapon and to its better visibility and positional possibilities.

Important contributions to the presentation and development of these advantages were achieved with the help of combat simulation and used as decision-making bases.

#198

TITLE: Spectral Analysis of Time Series Data: Considered as a Tool for Validating Simulation Models

AUTHOR: Michael A. Fabrizi

ORGANIZATION: US Army Aviation Systems Command
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ABSTRACT:

We consider a statistical technique for validation of computer simulations; that is, we attempt to answer the question, "Is this computer model an acceptably accurate portrayal of empirical reality"? We attempt to make this determination on the basis of a comparison of the variance of the simulation output, evaluated over the frequency domain, with that of historical time series data, similarly evaluated. Our study proceeds as follows: After reviewing the literature and giving some rationale for our approach to the problem, we discuss the concepts of spectral averages, with the attendant problems of aliasing and lag windows. Next, we address a technique for using spectral averages to compare simulation output with that of historical time series data, where both sets of data are held to represent the process under study. Lastly, we generalize the technique to compare K > 1 simulation models to the historical time series data.

#154

TITLE: A Statistical Test for the Validation of Computer Simulations

AUTHOR: Dr. Dwayne W. Nuzman

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

A new distribution free statistical test for model validation is presented. This test is intended to be used in conjunction with older graphical methods of validation.

A New Diagnostic Methodology for Evaluating Army Experiments

Dr. Jock O. Grynovicki

Human Engineering Laboratory, Aberdeen Proving Ground, MD 21005

1.1 Introduction

Repeated measures designs are some of the most frequently used class of designs in Army research. The traditional univariate analysis of the repeated measures design is obtained by treating subjects and their associated interactions as random effects. This analysis requires that certain variances and covariances of the dependent variable at various combinations of within-subject factors be equal. For example, in a three-way completely random factorial model, Cov $(Y_{ijkm}, Y_{ij^*k^*m^*})$ is assumed constant (ϕ_1) for all i and each combination of $j \neq j^*$, $k \neq k^*$ regardless of m and m^*. Instability of the variance and covariance components may mask significant effects or compel the researcher to use a less powerful multivariate technique, provided sufficient subjects are available. The number of subjects required in the multivariate approach is a function of the number of dependent variables and levels of the within-subject factors. Thus, the researcher may be forced to use a conservative degree-of-freedom adjustment instead, which may mask significant results.

1.2 Purpose

This paper illustrates the use of a recently developed class of unbiased variance component estimators and their associated diagnostics for examining the data and the model assumptions. The researcher, with the use of the distribution of the diagnostics, will be able to identify the source of the sphericity violation. Consequently, by modifying the model to account for unexplained sources of variability or removing outliers which may cause sphericity violations, a more powerful univariate analysis can be performed.

1.3 Repeated Measures Methodology

Repeated measures designs are some of the most frequently used classes of designs in Army research development and testing. These designs offer a reduction in the error variance because of the removal of an individual's variability. They are efficient and require fewer subjects to achieve the same power of the F-test as completely random or block designs.

This class of designs, sometimes referred to as within-subject designs, obtains its name from the fact that one or more factors of the design are manipulated in such a way that each subject receives all levels of the within-subject factor. One advantage of this approach is that subjects act as their own control in their responsiveness to the various experimental treatments. On the other hand, this type of design introduces intercorrelations among the means on which the test of within-subject main effects and interactions is based.

Because of this intercorrelation between the repeated treatments, three separate approaches have been proposed in the literature. They are (1) an univariate analysis using a mixed model, (2) a univariate mixed analysis with a degree of freedom adjustment, and (3) a multivariate analysis.

The first, the univariate analysis of the repeated measures design, is obtained by treating subjects as a random effect. The linear model employed is called a mixed effects model, and the resulting analysis is a mixed model analysis of the repeated measures design. The standard mixed model assumes certain variances and covariances of responses are invariant across the experiment.

In a three-factor factorial model with Factors 1 and 3 fixed and subjects (or factor 2) random, a standard assumption is that the covariance, θ_{12}, of responses at the same level of factor 1 and on the same subject (i.e., level of factor 2) but at different levels of factor 3, is invariant across all subjects, all levels of factor 1 and all combinations of distinct levels of factor 3. For example, for each level i of factor 1 and subject j, the variance of the a_3 x 1 vector $(\bar{Y}ijk.)_k' = (\bar{Y}ij1., \bar{Y}ij2., \ldots, \bar{Y}ija_3.)$ has the form $(\theta_{123} - \theta_{12})\, I_{a_3} + \theta_{13} J_{a_3} J_{a_3}'$, in which I_{a_3} is an a_3 x a_3 identity matrix and J_{a_3} is an a_3 x 1 vector of ones. The same covariance structure applies regardless of the value of i and j. Analogous statements apply to the a_1 by 1 vector $(\bar{Y}ijk.)_i$ for fixed j and k. This assumption is referred to in the literature as compound symmetry. More generally, for any design, if θ_t is the covariance between observations at the same levels of factors indexed by t and at different levels of the other factors, then standard mixed models assume θ_t is invariant across all levels of the factors indexed by t and across all combinations of distinct levels of the other factors.

A more general case in which the mean square ratio of a two factor model has an exact F distribution is described in Huynh and Feldt (1970). This condition, referred to in the literature as sphericity, requires that $C'\sum C = \sigma^2 I$, in which C is a (k-1) x k orthonormal contrast matrix, I is the identity matrix of rank (k-1) and $\sum$ is the variance-covariance matrix.

It should be noted that compound symmetry is a special case of sphericity. It has been stated in the literature that, although it is not necessary, the absence of compound symmetry does indicate that sphericity is unlikely (O'Brien and Kaiser, 1985). Several papers have appeared that state the assumption of sphericity is frequently violated. The consequence of such a violation is positive bias, meaning that the likelihood of a Type I error exceeds the nominal level, alpha (α). To test the sphericity assumption, or equivalently, the Huynh and Feldt Type H pattern, one uses the Mauchly (1940) test statistic. A weighted function of this statistic has a chi-square distribution with $(1/2)p(p-1)-1$ degrees of freedom. Here, p is the number of treatment levels under which the assumption is being tested.

To compensate for nonsphericity, a degree of freedom adjustment (ϵ), initially proposed for use by Greenhouse and Geisser (1959), is used to adjust the numerator and denominator degrees of freedom of the ratio. Huynh and Feldt (1970) have shown this adjustment to be too conservative. Values of ϵ range from 1, indicating sphericity to, $1/(k-1)$, indicating maximum nonsphericity. Since the population Σ is rarely known, one approach proposed by Greenhouse and Geisser is to use the lower limit $1/(k-1)$.

In the multivariate method, the responses of a subject are treated as a k dimensional response vector. It is worth noting that this approach is not as powerful as the univariate approach if the assumption of compound symmetry is accepted.

Unfortunately, neither the ϵ adjustments nor the multivariate approach protect the subtests that typically follow. This is particularly unfortunate, since these subtests are used to clarify significant overall comparisons and they are susceptible to bias under nonsphericity.

Difficulty in interpretation can occur when several dependent measures are made for each experimental treatment and the assumption of compound symmetry is rejected. This situation can result in a lack of degrees of freedom and power since the dimension of the response matrix, which is a multiple of the number of dependent variables and the number of unique within-subject factor treatment combinations, can equal or exceed the total number of subjects. In the multivariate context, this can result in the degrees of freedom parameter being very small. If the number of subjects is less than the number of unique within-subject treatment combinations, the overall multivariate test cannot be computed.

Since it is common and necessary to record, evaluate, and analyze numerous measurements during experimentation, alternate approaches to assess the effect of treatment conditions on the response measurements need to be explored. This paper introduces and demonstrates the use of unbiased, efficient variance component estimators, their associated diagnostics and distribution to detect assumption violations concerning the repeated measures design. By identifying the source of the sphericity violation, the researcher would be able to modify the underlying linear model to account for the unexplained variability or remove outliers which may result in the acceptance of the sphericity assumption. Thus, a more powerful simpler univariate repeated measures approach can be undertaken which may require smaller sample size.

1.4 General Variance Component Estimates and Diagnostics Methodology

The problem of estimating variance components in random and mixed models has been of interest to researchers for years. However, over the last few years, new closed form expressions for the estimators of variance components have been proposed, based on the equivalence shown in Green (1985, 1987); Hocking, et al. (1989); and Hocking (1985) of the variance component estimation problem to the problem of estimating the covariances, θ_t, between appropriately related observations. In addition, the distribution of these estimators has been developed and demonstrated (Grynovicki, 1989) to provide information useful in evaluating the mixed or random model, identifying outliers and checking underlying assumptions, diagnosing problems, and suggesting simple graphical procedures for examining the influence of the treatment levels.

To introduce this general methodology, this chapter will only consider three-factor repeated measures design with factors one and three repeated. The number of levels of factor (i) is designated by a_i. Subjects are designated factor 2. Factors 1 and 3 are the within-subject fixed factors. The traditional univariate repeated measures model with subjects and subject interactions considered random is

$$Y(ijkm) = M+A(i)+S(j)+AS(ij)+B(k)+AB(ik)+SB(jk)+ABS(ijk)+\epsilon(ijkm), \quad (1.1)$$

in which M is the overall mean; A(i) is the effect of level i of treatment or factor A; S(j) is the effect of subject j; AS(ij) is the effect of level ij of treatment combination AS; B(k) is the effect of level k of factor B; AB(ik) is the effect of the AB treatment combination at level ik; SB(jk) is the effect of treatment combination SB at level (jk); ABS(ijk) is the effect of level ijk of treatment combination ABS; and ϵ(ijkm) is the random error. For the traditional univariate approach, it is assumed that A(i), B(k), AB(ik), and M are fixed and S(j), AS(ij), SB(jk), ABS(ijk), ϵ(ijkm) are zero mean, independent normal random variables with variances ϕ_2, ϕ_{12}, ϕ_{23}, ϕ_{123}, and ϕ_0, respectively. While the variables are independent, the responses are correlated, with

$$\begin{aligned}
\theta_2 &= \phi_2, \text{ if } i \neq i^*,\ j = j^*,\ k \neq k^*, \\
\theta_{12} &= \phi_2 + \phi_{12}, \text{ if } i = i^*,\ j = j^*,\ k \neq k^*, \\
\theta_{23} &= \phi_2 + \phi_{23}, \text{ if } i \neq i^*,\ j = j^*,\ k = k^*, \\
\theta_{123} &= \phi_2 + \phi_{12} + \phi_{23} + \phi_{123}, \text{ if } i = i^*,\ j = j^*,\ k = k^*,\ m^* \neq m, \\
\text{and } \theta_0 &= \phi_0 + \theta_{123}, \text{ if } ijkm = i^*j^*k^*m^*.
\end{aligned} \quad (1.2)$$

This covariance structure suggests an alternate approach to the linear model first proposed in Hocking (1983) and extended and developed in Green (1985), and Grynovicki (1987,1989) to several classes of linear models. This approach relaxes the requirement that the variance components be positive. Thus, the classical model is replaced by specifying the response vector to be normal with covariance matrix as previously given in (1.2) and mean vector determined from the expectation of Y, as

$$E(Y_{ijkm}) = M + A(i) + B(k) + AB(ik). \tag{1.3}$$

The only restriction on the covariance matrix is that it be positive definite. This requirement is weaker than the classical requirement that the ϕ_t be positive. An in-depth development of this alternate model is contained in Hocking (1985). In this notation, θ_t is between observations at the same level of factors indexed by t and different levels of all other factors in the model. This suggests examining the corresponding sample covariances. These sample covariances yield the estimators of the θ_t. Sample covariances yielding estimators of θ_2 and θ_{12} are

$$\hat{\theta}_2 = \frac{1}{a_{13}\ r_{13}} \sum_{ik\neq i^*k^*} \frac{1}{r_2} \sum_j (\bar{Y}ijk. - \bar{Y}i.k.)(\bar{Y}i^*jk^*. - \bar{Y}i^*.k^*.), \text{ and} \tag{1.4}$$

$$\hat{\theta}_{12} = \frac{1}{a_{13}\ r_3} \sum_{k\neq k^*} \frac{1}{r_2} \sum_{ij} (\bar{Y}ijk. - \bar{Y}i.k.)(\bar{Y}ijk^*. - \bar{Y}i.k^*.),$$

in which $\sum_{ik\neq i^*k^*}$ is the sum over $i \neq i^*$ and $k \neq k^*$ and $\sum_{ik}$ is the sum across all i and j. Similarly, θ_{23} is analogous to the θ_{12} estimator with subscripts i and k interchanged.

From (1.4), one recognizes the θ_2 estimator as the average of a_{13} x $r_{13}/2$ equal expectation sample covariances corresponding to all combinations of $i \neq i^*$, $k \neq k^*$. As written, each sample covariance appears twice. Here, $r_i = a_i-1$. Similarly, θ_{12} is the average of a_{13} x $r_3/2$ equal expectation sample covariances corresponding to all combinations of $i \neq i^*$ and $k \neq k^*$.

These covariances are unbiased and contain the diagnostic power. By plotting these covariances (diagnostics) in table form, one obtains an indication of the stability of the estimate. For example, consider displaying the a_{13} x r_{13} sample covariances or diagnostics for θ_2, corresponding to $i \neq i^*$, ck $\neq k^*$ into a_1 x $r_1/2$ tables each of dimension a_3 by a_3. In these tables, the off-diagonal terms are the distinct sample covariances associated with different levels of factor and factor 3 and the same level of factor 2. Also, for the three-factor design, consider θ_{12}. One displays the a_1 x a_3 x $r_3/2$ sample covariances in a_1 tables of dimension a_3 x a_3. In these tables, the above diagonal elements are the a_3 x $r_3/2$ distinct sample covariances associated with levels i, of factor 1 and level k of factor 3, with all a_2 levels of factor 2 used to determine the sample covariances.

In general, using the distribution theory developed by Grynovicki (1989), one looks for outliers and trends. For example, (1) unusually large or small diagonal entries indicate abnormal variability in the cell means for this level of the factor under investigation; (2) special patterns in the off-diagonal elements, such as a particular column or row having the majority of its entries higher or lower than other rows or columns, indicate one or more cells may contain extreme outliers, or unexpected deviations from model assumptions occur; and (3) large fluctuations in the off-diagonal entries reflect high variability in the data.

Following the examination of the diagnostics, plots of treatment i versus treatment i^* cell-means, in which abnormal diagnostics have been identified, are recommended. This will help the researcher identify the treatment cells responsible for extra large or small variance component estimates. Finally, the diagnostic procedure should conclude with an examination of the data in the identified cells.

1.5 Repeated Measure Design

To illustrate these diagnostic procedures, data from a repeated measures design conducted by Malkin and Christ (1987) will be used. The objective of the experiment was to conduct a laboratory flight simulation to compare a cockpit keyboard, a thumb-controlled switch, and a connected-word voice recognizer for data entry of navigation map coordinate sets when (1) the entry of Universal Transverse Mercator (UTM) coordinate sets is the sole task performed (no flight) and (2) the entry of UTM coordinate sets is performed concurrently with controlling a helicopter simulator while flying a computer-generated external scene (flight). For this paper, the differences among the three methods of data entry input time will be evaluated for both the flight and no-flight conditions. The original paper also investigated subje. . error and response time.

1.6.1 Methodology

Data were collected using 12 aviators assigned to Aberdeen Proving Ground, Maryland as experimental subjects. The Aviation and Air Defense Division, Human Engineering Laboratory's flight simulator was used for this study. The crew simulator consists of a cockpit cab with advanced controls and displays and an "out-the-window" scene produced by computer-generated imaging (CGI). The CGI, cockpit controls, flight simulation, displays, and results were driven or recorded using two Digital Corporation VAX computers. Training was administered to all subjects in the operation of the voice recognition system and flight simulator. For an in-depth accounting of the apparatus and training, the reader is referred to Malkin and Christ (1987).

1.6.2 Experimental Design

A 2x3x12 factorial design with repeated measures for the 12 subjects was implemented. The within-subject factors were data entry methods (voice, keyboard, and thumb-controlled switch) and task conditions (flight, no flight).

Table 1.1

DIAGNOSTICS

INPUT TIME

$\boxed{\theta_2}$

NO FLIGHT

		VOICE	KEYBOARD	THUMB
FLIGHT	VOICE	76.20	-13.80	-12.47
	KEYBOARD	13.68	4.80	16.01
	THUMB	40.78	1.88	35.10

1.6.3 Results

Since the response measures were highly correlated, and only 12 subjects were used, a multivariate analysis of variance was performed with task and method fixed and subjects considered a random factor. This approach is suggested by Schutz and Gessorali (1987). The approximate F-ratios were then checked against the Greenhouse-Geisser adjustment, and they agreed.

There were significant differences among the three mean input times for the data entry method. Subjects were able to input data faster during the no-flight task conditions than during the flight conditions. However, there was no significant interaction between task and entry method.

As a final note, the input time covariances for the within-subject factors showed extreme deviation from the sphericity assumption. An in-depth analysis for input time will be provided, which will demonstrate the use of these diagnostics and their distribution for checking and identifying assumption violations.

1.7 Illustrated Example of Variance Component Estimates and Diagnostics

As previously noted, it is natural to estimate the covariances θ_t by corresponding sample covariances. In the balanced case, and for the Malkin-Christ data, the estimates can be obtained from the ANOVA table by equating mean squares to expected mean squares. Based on this method, the estimates for input times were calculated as $\hat{\phi}_2 = 7.68$, $\hat{\phi}_{12} = 31.03$, $\hat{\phi}_{23} = 3.35$, $\hat{\phi}_{123} = -5.49$, $\hat{\phi}_0 = 305.26$.

For this example, $a_1 = 3$, $a_2 = 12$ and $a_3 = 2$. The estimate of θ_2 is the average of six distinct sample covariances. They can be displayed in a table such as Table 1.1 for input time. The elements are the sample covariances. To avoid confusion, it is worth noting that the diagonal elements are not true variances since $k \neq k^*$.

Under the covariance structure and compound symmetry assumption, all off-diagonal elements of Tables 1.1 should be approximately equal as well as all diagonal elements. Therefore, the diagnostics provide an illustrative procedure to check the compound symmetry assumption and identify treatment combinations that indicate violation of this assumption.

In examining the θ_2 off-diagonal diagnostics of Table 1.1, the diagnostic of (40.78) for thumb flight versus voice no flight was outside the 90th percentile based on an estimated variance of 74.72 and correlation of 0.10. These estimates are obtained from the variance components estimated previously. The variance is equal to $\hat{\phi}_2 + \hat{\phi}_{12} + \hat{\phi}_{23} + \hat{\phi}_{123} + \hat{\phi}_0/8$, and covariance is $\hat{\phi}_2$.

This suggests further examination of the specified treatment combinations. Follow-up plots of subject mean input times by treatment combinations, reflecting

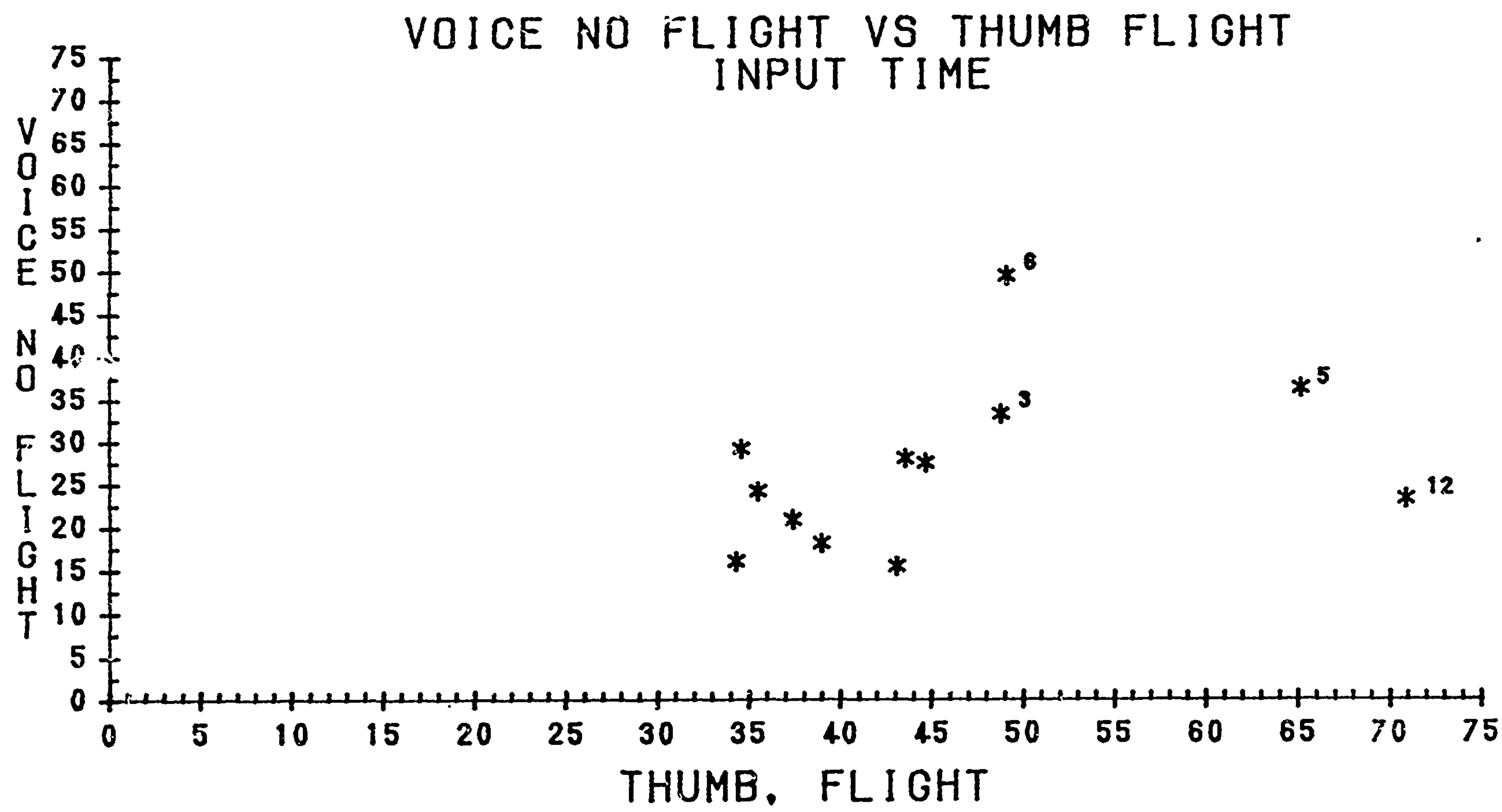

Figure 1.1: Malkin and Christ DATA: Subject cell means of Voice No Flight VS Thumb Flight. Plotting Symbol: numbers represent a distinct subject.

the large or small covariances, are shown in Figure 1.1. Examination of these plots reveals that for subjects 3, 5, 6, and 12, input time contributed to the extremely high or low covariances.

The diagnostic plots for θ_{12} and θ_{23} are shown in Table 1.2. The cell means for θ_{12} had an estimated variance of 74.72 and correlation of 0.51. Based on these estimated parameters, and N = 12, the distribution revealed that the variance component of 76.2 for voice no flight versus voice flight and (4.6) for keyboard no flight versus keyboard flight was in the 92th and 5th percentiles. A follow-up plots for the large and small covariances indicated that subjects' 2, 3, 5, and 6 input times contributed to this large covariance.

Identifying what seemed to be a dichotomous population of subjects, a review of subject records was undertaken to attempt to explain the reason several subjects seemed to respond differently from the rest of the subjects. A review of the records indicated that, in general, these pilots were older (over 42 as compared to under 38), had a higher military rank, and had spent as much time or more flying fixed wing as rotary wing aircraft, with recent flying experience concentrated on fixed wing. Subject 2's records on demographics were missing. However, based on his response, he will be considered part of the fixed wing group. Based on subjective input from experienced pilots, differences between the aircraft in regard to instrumentation and flying procedures could certainly account for the difference in input times between fixed wing and rotary wing pilots.

1.8.1 Adjusted Linear Model

The repeated measures design conducted by Malkin and Christ (1987) was re-analyzed considering pilot type (fixed rotary) as an additional variable in the model. The reason for this additional factor is that the previous analysis identified a dichotomy in the subject population. The majority of flying time for subjects 2, 3, 5, 6, and 12 was in a fixed wing aircraft while the remaining seven subjects flew a rotary wing aircraft.

1.8.2 Results

There was a significant difference between the three mean input times, which agreed with the previous results and is shown in Table 3.4. Input time was faster for the keyboard than for voice or thumb switch. This difference was magnified for the fixed wing pilots and contributed to a significant interaction between pilot type and input time. Subjects were also able to input data faster when not flying than when flying. However, this difference was larger for rotary than fixed wing pilots, which accounts for the pilot type interaction. As expected, fixed wing pilots were slower to input data than were rotary pilots. Mauchly's criteria for testing sphericity was not significant for the task, method, or method-by-task effect. Thus, by re-defining the linear model and accounting for the additional source of variability, the assumption underlying the more powerful univariate approach could not be rejected.

Table 1.2

DIAGNOSTICS

INPUT TIME

$\boxed{\Theta_{12}}$

METHOD (l)

1*=1	VOICE TASK (k) NO FLIGHT (1)	VOICE TASK (k) FLIGHT (2)	KEYBOARD TASK (k) NO FLIGHT (1)	KEYBOARD TASK (k) FLIGHT (2)	THUMB TASK (k) NO FLIGHT (1)	THUMB TASK (k) FLIGHT (2)
NO FLIGHT	95.3	76.2	5.1	4.6	24.09	35.1
FLIGHT	76.2	19.9	4.6	38.7	35.1	138.1

$\boxed{\Theta_{23}}$

TASK (k)

NO FLIGHT METHOD (l)

	VOICE	KEYBOARD	THUMB
VOICE	95.3	-5.9	23.1
KEYBOARD	-5.9	5.1	0.2
THUMB	23.1	0.2	24.1

FLIGHT METHOD (l)

	VOICE	KEYBOARD	THUMB
VOICE	199.0	-5.0	10.5
KEYBOARD	-5.0	38.7	43.2
THUMB	10.5	43.3	138.2

DIAGNOSTIC C

1.9 Variance Component Estimates and Diagnostics

The Restricted Maximum Likelihood (REML) variance component estimates for input time were ϕ_{24} = 3.06, ϕ_{124} = 17.01, ϕ_{234} = 5.86, and ϕ_0 = 305.26. For this model, we will denote a_{21} = 5 and a_{22} = 7 as the number of pilots that are fixed wing and rotary, respectively. As in the previous section, a_1 = 3 and a_3 = 2. The estimate of θ_{24} is the average of six distinct sample covariances for each of the two pilot types. The diagnostics for θ_{24} are displayed in Table 1.3. For input time, the independent pairs of observations comprising the bilinear form for this diagnostic have an estimated variance of 64.05 and correlation of 0.047. Based on the distribution theory, all six diagnostics for rotary wing pilot are between the 10th and 85th percentile [-28, 30], and for fixed wing, they are all between the 5th and 90th percentile [-39, 43].

The diagnostics for θ_{124} for input time are in Table 1.4. The variance of the observations comprising the bilinear form for input time is 64.95 seconds and has a correlation of 0.26 seconds. All of the diagnostics for θ_{124}, except for one, were between the 20th and 80th percentile. The diagnostic for thumb flight versus no flight (93.62) fell above the 95th percentile. This can be attributed to the two outliers. One of these values was in cell thumb flight, subject 5, fixed wing and the other was in the thumb flight, subject 12, fixed wing cell. Removal of these values, remembering that the experiment had been repeated eight times, reduced the covariance to 69.43, which is below the 95th percentile.

The correlation of the paired cell means comprising the diagnostics for θ_{234} was 0.09. All of these diagnostics, based on input time, fell between the 10th and 95th percentile.

1.10 Conclusions

The distribution of the diagnostics for a sample of independent observations from $N_2(\mu, V)$ for even and odd sample size has been developed, tabulated, and validated. This theory has been extended to the diagnostic tables inwhich the covariances are not independent, and it has been proved useful as a diagnostic tool. Based on this procedure, one can conclude that the model is quite satisfactory.

The diagnostic procedures have been demonstrated effective in checking underlying assumptions (compound symmetry) of the linear model and useful in identifying the probable cause for the violation of these assumptions. Thus, an alternate diagnostic approach is proposed that provides the researcher the options of removing spurious observations, performing transformations, controlling additional sources of variability so that the data can conform to the standard assumptions, or modifying the model.

Table 1.3

DIAGNOSTICS

INPUT TIME

$\boxed{\Theta_{24}}$

ROTARY WING PILOTS

NO FLIGHT

FLIGHT		VOICE	KEYBOARD	THUMB
	VOICE	37.15	0.48	24.07
FLIGHT	KEYBOARD	-13.01	0.86	-3.78
	THUMB	1.93	8.11	4.84

FIXED WING PILOTS

NO FLIGHT

FLIGHT		VOICE	KEYBOARD	THUMB
	VOICE	-6.00	-3.34	-5.25
FLIGHT	KEYBOARD	9.07	14.80	17.37
	THUMB	-38.21	23.88	93.62

Table 1.4

DIAGNOSTICS
INPUT TIME

$\boxed{\theta_{124}}$

ROTARY WING PILOTS

	VOICE flight	VOICE no flight	KEYBOARD flight	KEYBOARD no flight	THUMB flight	THUMB no flight
Flight	35.03	37.15	6.80	0.86	15.96	4.85
No Flight	37.15	90.68	0.86	12.61	4.85	39.66

FIXED WING PILOTS

	VOICE flight	VOICE no flight	KEYBOARD flight	KEYBOARD no flight	THUMB flight	THUMB no flight
Flight	118.08	-6.00	3.37	14.80	38.71	93.62
No Flight	-6.00	211.90	14.80	69.81	93.62	282.75

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STATISTICAL PRECISION AND ROBUSTNESS OF THE AMSAA CONTINUOUS RELIABILITY GROWTH ESTIMATORS.

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KEY WORDS -- Reliability growth model, Statistical precision of MIL-HDBK-189 MTBF estimators, Robustness of MIL-HDBK-189 MTBF estimators.

ABSTRACT -- The statistical precision and robustness study of the AMSAA continuous reliability growth estimation procedure investigates the relative error distribution of the MTBF estimator. The study also addresses how this distribution is influenced when the failure data are generated from a finite number of configurations rather than from the AMSAA continuous failure rate curve. This methodology can be used to calculate the required test time associated with an idealized planning curve to achieve a specified precision with a given probability.

1. BACKGROUND

The U.S. Army Materiel Systems Analysis Activity (AMSAA) employs the Weibull process to model reliability growth during a development test phase. This model was developed by Larry H. Crow, while still at AMSAA. Development test programs are generally conducted on a phase by phase basis. The AMSAA reliability growth model is designed for tracking the reliability within a test phase (Reference 1). This model evaluates the reliability growth that results from the introduction of design fixes into the system during test. Figure 1 illustrates a typical pattern of growth on a phase by phase basis. The AMSAA tracking model addresses the reliability growth within a particular test phase. Several

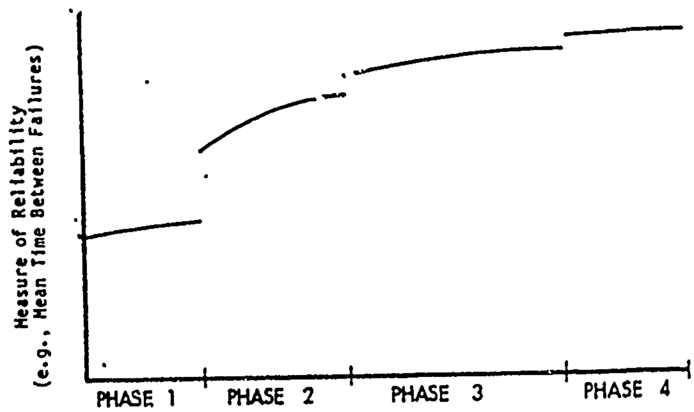


Figure 1. Measure of Reliability (e.g., Mean-Time-Between-Failures (MTBF) in Different Phases.

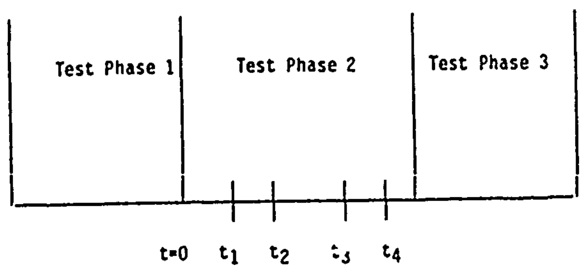


Figure 2. Times of Design Modifications for Test Phase 2.

tracking growth curves may be required to measure reliability growth over multiple test phases due to the incorporation of groups of fixes between test phases and/or changes in test phase environments. Assume the test phase starts at time t=0. Within the test phase, let 0<t1<t2<...<tk denote the cumulative test times on the system when design modifications are made (see Figure 2). The failure rate can generally be assumed to be constant between the times when design changes are made on the system.

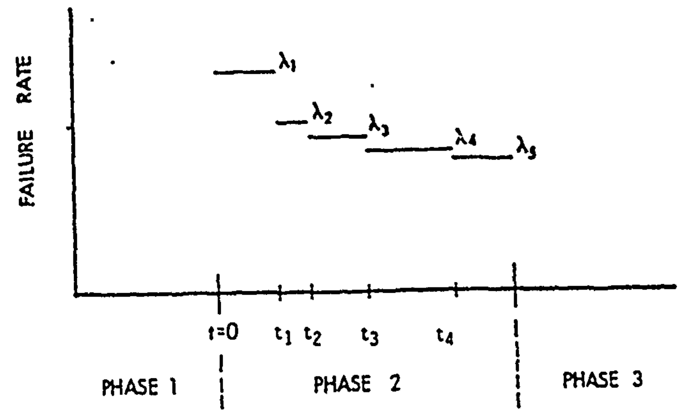


Figure 3. Failure Rates Between Modifications.

Let λ_i denote the constant failure rate during the ith time period $[t_{(i-1)}, t_i]$ between modifications (see Figure 3). The constant failure rate assumption during $[t_{(i-1)}, t_i]$ implies that for this interval, the times between successive failures follow the exponential distribution $F(x) = 1 - \exp(-\lambda_i x)$, $x>0$. The AMSAA tracking model approximates the step-wise failure rate function shown in Figure 3 by a smooth curve. The parameters of this curve are estimated, based upon the failure data observed during the test phase.

1.1 STUDY OBJECTIVES

a. Study the statistical precision of the AMSAA MIL-HDBK-189 (Reference 2) mean time between failure (MTBF) estimators $\hat{M}$ and $\bar{M}$.

b. Study robustness, i.e., the effect on estimator statistical precision due to discrete configuration changes (i.e., the step-wise discontinuous failure rate curve).

2. PRECISION

The statistical precision of the AMSAA (MIL-HDBK-189) mean time between failure (MTBF) estimators $\hat{M}$ and $\bar{M}$ was measured by the Relative Error, RE, defined by $RE = |M_{(EST)} - M_{(TRUE)}| / M_{(TRUE)}$ where $M_{(EST)} = \hat{M}$ or $\bar{M}$. The estimator $\hat{M}(\bar{M})$ may be calculated from the maximum likelihood estimator $\hat{\beta}$ (unbiased estimator $\bar{\beta}$) of the shape parameter β . In the above, $M_{(TRUE)}$ denotes the true but unknown MTBF at the end of the test time. Since $M_{(EST)}$ is a random variable, RE is a random variable. Thus, one can consider the distribution of RE which determines the probability of RE being less than or equal to a specified relative error. This paper addresses the relationship between this distribution and the parameters that define an idealized reliability growth planning curve. The method of maximum likelihood utilized in the MIL-HDBK-189 provides the estimate of the shape parameter β

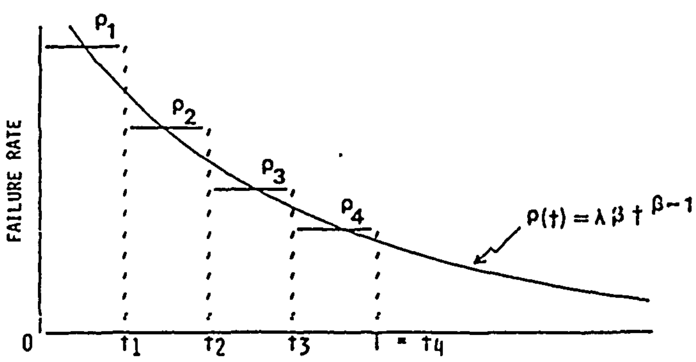
through the formula: $\hat{\beta} = N/(N \ln T - \sum_{i=1}^{N} \ln f_i)$
where f1<f2<f3<...<fN are the N successive failure times, which occur during a test phase of duration T. Subsequently, the scale parameter λ is estimated by $\hat{\lambda} = N/T^{\hat{\beta}}$. It follows that for any time t, the intensity function (failure rate) is estimated by $\hat{\rho}(t) = \hat{\lambda}\hat{\beta}t^{\hat{\beta}-1}$. In particular this holds for T, the total test time. The reciprocal of $\hat{\rho}(T)$ provides an estimate of the MTBF, which could be anticipated if the system configuration remains as it is at time T. This estimate is denoted by $\hat{M}$. Thus, $\hat{M} = 1/\hat{\rho}(T) = T/N\hat{\beta}$. For small sample sizes, it is appropriate to use an unbiased estimator $\bar{\beta}$ of the shape parameter β. The estimator $\bar{\beta}$ is defined as $\bar{\beta} = ((N-1)/N)\hat{\beta}$ for N>=2. In this study, $\bar{\beta} = \hat{\beta}$ for N=1. Note that the estimator $\bar{\beta}$ is unbiased only for the case N>=2. The estimator $\bar{M}$ for MTBF can be calculated by using the formula:

$$\bar{M} = \hat{M} \text{ for } N=1; \quad \bar{M} = T/N\bar{\beta} \text{ for } N \geq 2.$$

The above formulation applies to time-terminated testing. In this study we simulated 5,000 failure histories for estimating the probability of achieving precision with $\hat{M}$ and $\bar{M}$. The estimated probabilities were conditioned on the set of failure histories that had at least one failure. For each simulation run, the number of failures N and cumulative failure times f1,f2,f3,...,fN were recorded. The total test time T was chosen to be 1,000 hours, 5,000 hours, and 10,000 hours. For each test length, the MTBF estimators $\hat{M}$ and $\bar{M}$ were calculated and, thereby, the distribution of relative error was obtained to analyze the behavior of the MTBF estimators. It was found that the probability of achieving a specified precision (i.e., specified relative error) depends solely upon the expected number of failures. In fact, an analytical expression in terms of the expected number of failures can be found for the distribution function of the relative error (Reference 3). Also note that $\hat{M}$ and $\bar{M}$ behave in the same way, especially when the expected number of failures is moderate to large (see Figs. 4 & 5).

3. ROBUSTNESS

A class of step functions compatible with the AMSAA tracking model was considered. For simplicity, the total test time T was divided into s equal size sub-intervals. For each sub-interval i (i=1,2,...,s), the constant failure rate ρ_i was defined as the average value of $\rho(t) = \lambda\beta t^{\beta-1}$ over sub-interval i. Figure 6 illustrates the construction for the case s=4. In the step function construction, the steps represent the constant failure rates over different configurations. By simulation the failure data were generated from the step function failure rate curves, and then



ρ_i = HEIGHT OF ith RECTANGLE (i=1,2,3,4)

t_i = i (T/s) = i(T/4)

Figure 6. Step Function Failure Rate Curve.

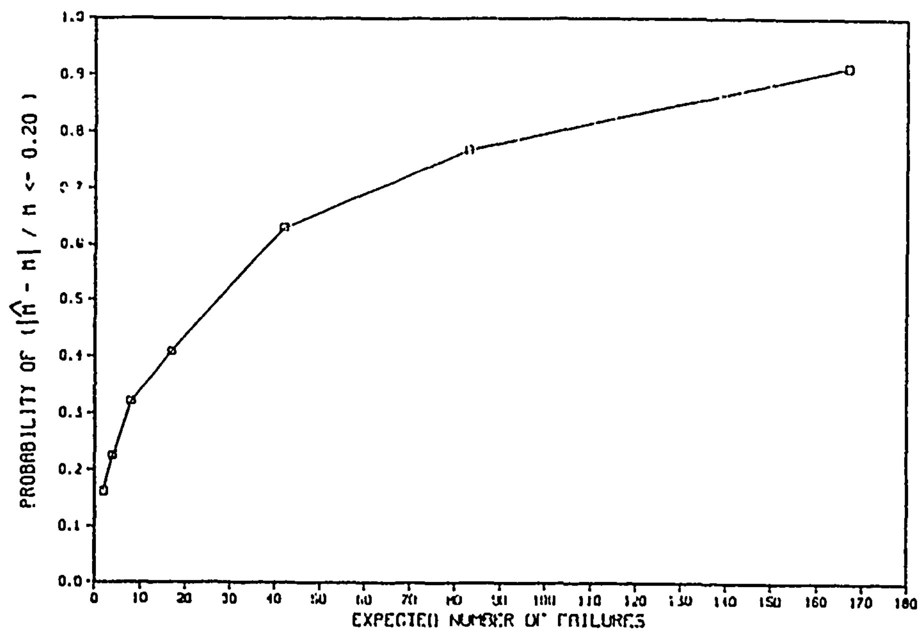


Figure 4. Probability of 20% Precision vs. Expected Number of Failures for $\hat{N}$

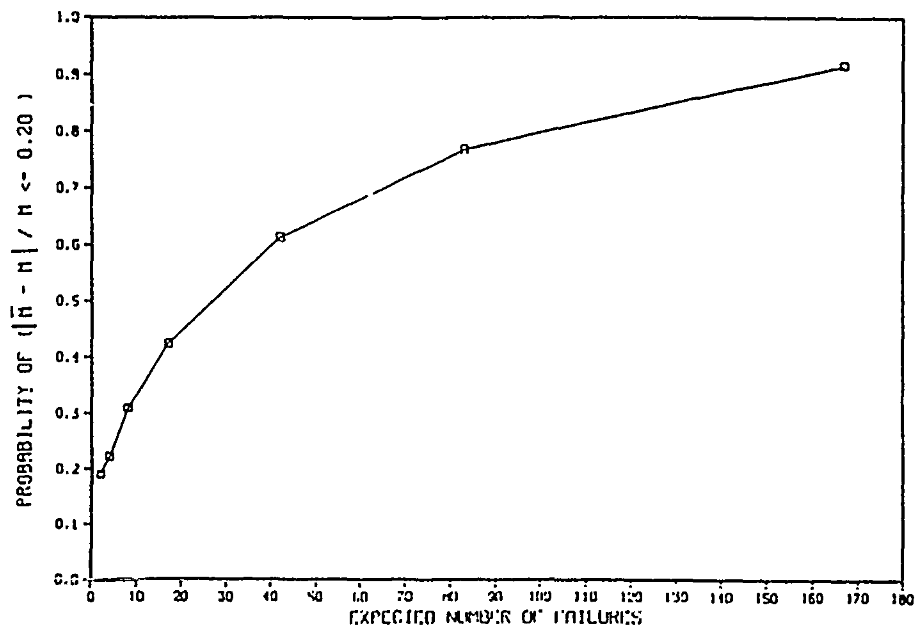


Figure 5. Probability of 20% Precision vs. Expected Number of Failures for $\bar{N}$

MIL-HDBK-189 estimators $\hat{M}$ and $\bar{M}$ were computed as in Section 2. For both estimators, the distributions of RE, defined in Section 2 were computed. For the step function construction, $M_{(TRUE)}$ is the MTBF of the system's last configuration. From the simulation results for the discrete failure rate curve, it was observed that the probability of achieving a specified precision strongly depends upon the expected number of failures and weakly upon the number of configurations for about five or more configurations as shown in Figures 7 and 8. Notice that the estimators $\hat{M}$ and $\bar{M}$ behave in the same way. It is important to note that the probability of achieving a specified precision for a finite number of configurations approaches the probability obtained for the smooth AMSAA failure rate curve, as the number of configurations increases.

4. COMPUTATIONAL EXAMPLES

4.1 Determine the amount of test time to achieve a specified precision with a given probability.

As an example of this type of problem, the amount of test time shall be calculated to ensure with a probability of 0.80 that the MTBF estimator $\hat{M}$ will be within 20 percent of the true (unknown) MTBF, $M_{(TRUE)}$.

Typically, one attempts to develop an idealized growth curve that will grow to a desired value, M_F. This value, M_F, may be the required MTBF, or it may be a value higher than the required MTBF. The latter case will occur when one is required to demonstrate the desired system's MTBF at a specified confidence level. In either event, it will be assumed in this example that the end point of the planning curve has been determined and denoted by M_F. Assume the growth actually occurs along the idealized curve to the end point after T hours. Then $M_{(TRUE)}$ will equal M_F. In this example, a value for T will be calculated, which will ensure with a probability of 0.80 that $|\hat{M} - M_{(TRUE)}| <= (0.20)\, M_{(TRUE)}$. This value of T depends on the expected number of failures associated with the idealized growth curve. The expected number of failures required to ensure a specified relative error with a probability of 0.80 can be found from a family of "Specified Relative Error vs Expected Number of Failures" curves (see Figure 9). It can be shown that the expected number of failures, E(F), may be expressed as: $E(F) = (1/(1-\alpha))\,(T/M_F)$. Thus for an assumed growth rate, for example $\alpha = 0.2$, specified precision = 0.2 and $M_F = 168$ hours, it can be seen from Figure 9, that E(F) = 93 and T may be calculated as follows:
$T = (1-\alpha)\,(M_F)\,(E(F)) = (1-0.2)\,(168)\,(93) = 12499.2$ hours.
Notice that for a given M_F and E(F), there is a linear relationship between the test time, T, and the growth rate, α. The idealized growth curve that corresponds to the specified growth rate of 0.2 and that grows to the desired MTBF, $M_F = 168$ hours in an amount of time, T = 12499.2 hours can be completely specified by using the relationship, $E(F) = \lambda T^{\beta}$ where $\beta = 1-\alpha$. Solving for λ, we obtain, $\lambda = (E(F))T^{-\beta}$. The equation of the idealized growth curve is now completely specified.

4.2 For a given amount of test time, T, and MTBF value, M_F to be achieved at the end of the test time, T, what precision

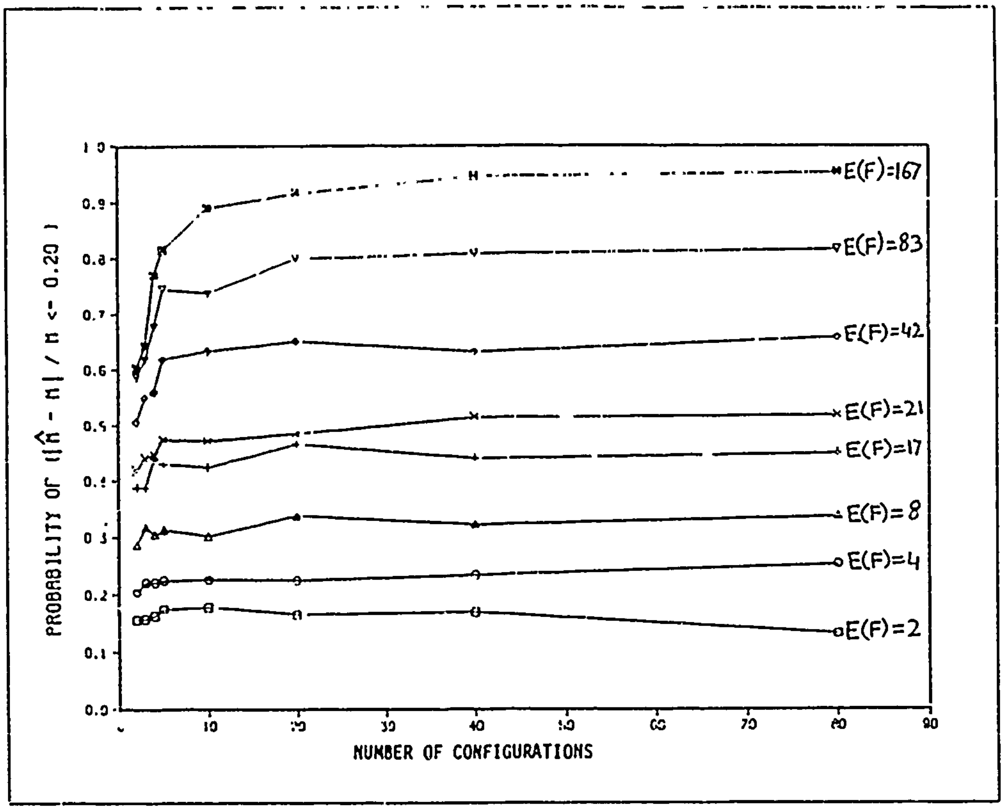


Figure 7. Probability of 20% Precision vs. Number of Configurations for $\hat{N}$

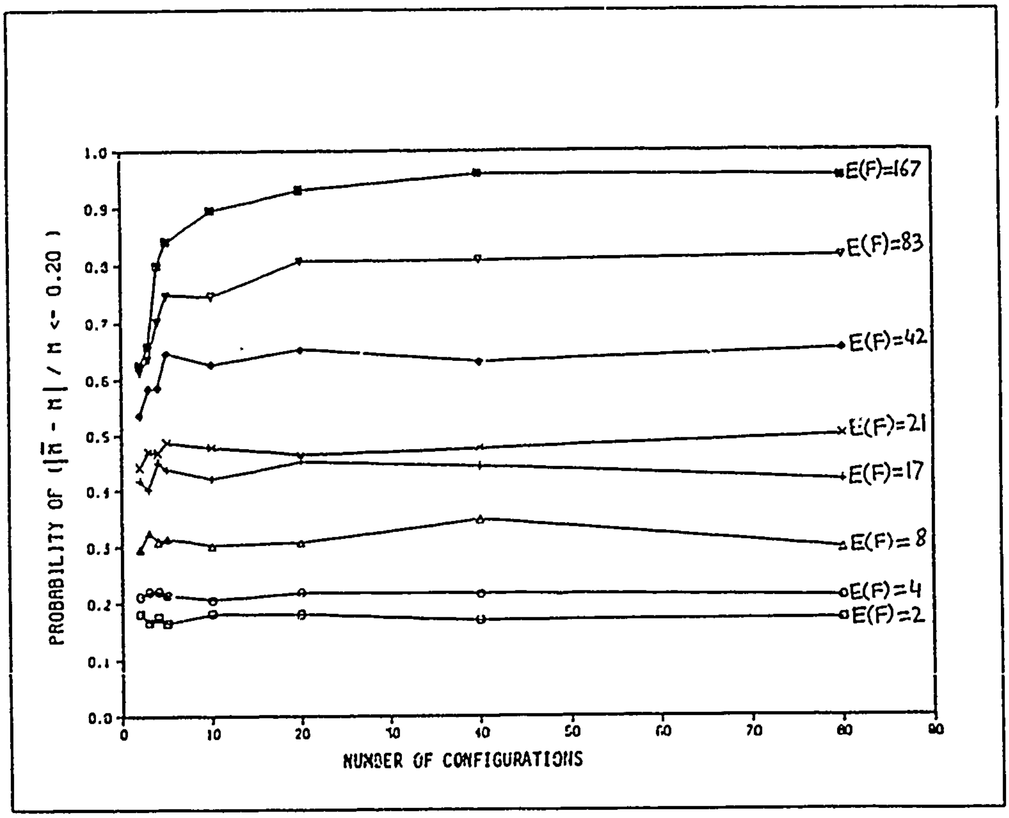


Figure 8. Probability of 20% Precision vs. Number of Configurations for $\bar{N}$

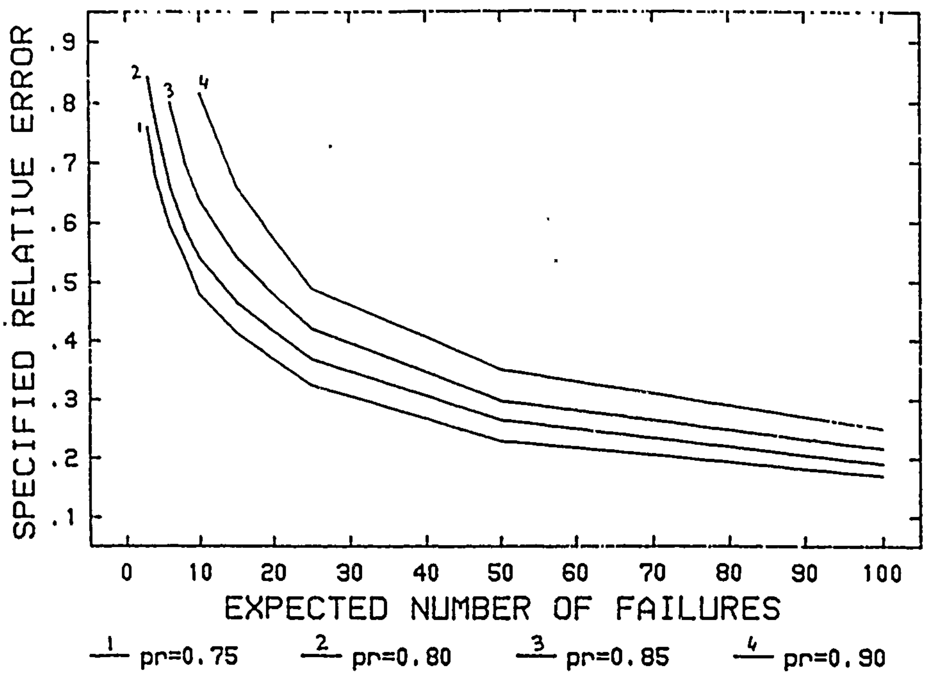


Figure 9. Specified Relative Error vs. Expected Number of Failures

(i.e., relative error) of the $\hat{M}$ estimator can be ensured with a specified probability for a stated growth rate?

In our example, the given amount of test time will be T=3542 hours and M_F will be taken to be 197 hours. We wish to calculate the precision of the $\hat{M}$ estimator that can be achieved with a probability of 0.80 for a growth curve with growth rate $\alpha = 0.3$.

The expected number of failures, E(F), can be calculated to be 26 by using one of the following formulas:

$$E(F) = (1/(1-\alpha))\ (T/M_F) \text{ or } E(F) = \lambda T^{\beta} = \lambda T^{(1-\alpha)} .$$

From Figure 9, it can be seen that PROB (RE <= 0.36) = 0.80.

5. CONCLUSIONS

5.1 From Section 2 regarding precision, it is concluded that:

5.1.1 The probability of achieving a specified precision increases as the expected number of failures increase.

5.1.2 The precision of $\hat{M}$ and $\bar{M}$ is essentially the same.

5.1.3 It is important to choose idealized planning curve parameters (T,α,λ) to obtain adequate precision for the estimator at the desired probability level. In particular, one should state the specified precision (i.e., specified relative error), RE_S, and probability level, PR, where

$$\text{PROB}\left(\frac{|M_{(EST)} - M_{(TRUE)}|}{M_{(TRUE)}} <= RE_S\right) = PR$$

5.1.4 For a given idealized planning curve and test time, one can calculate the risk that the estimate will not be within a specified percent of the true MTBF, e.g., for the specified percent = 20 percent

$$RISK = PROB\ (|M_{(EST)} - M_{(TRUE)}| > 0.20\ M_{(TRUE)})$$

5.1.5 This study emphasizes the need to include the confidence bounds on the true MTBF when presenting evaluations based on the MIL-HDBK-189 MTBF estimators. It could be misleading to only present point estimates in cases where the probability of obtaining good precision is low.

5.2 From Section 3 regarding robustness, it is concluded that:

5.2.1 The precision of MIL-HDBK-189 estimators strongly depends on the expected number of failures.

5.2.2 The robustness of $\hat{M}$ and $\bar{M}$ is essentially the same.

5.2.3 For a small expected number of failures, although the probability of achieving a specified precision is low, it is robust with respect to the number of configurations.

5.2.4 For a high expected number of failures, the probability is not robust for a small number of configurations. This emphasizes the need for instituting test, analyze, and fix (TAAF) procedures for long duration growth programs when the expected number of failures is high.

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Optimizing A System's Maintenance Policy

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ABSTRACT. The objective of this article is to determine the optimal balance between a repair versus a discard maintenance policy. It is shown that an optimal maintenance policy could be a composite of the pure policies. An example of a composite maintenance policy might be repair a component ninety percent of the time and throw it away replacing with a new component the other ten percent of the time. Because a component might require 1.1 pieces of equipment to support a pure repair policy and equipment can only be purchased in integral numbers, it may be optimal to buy only one piece of equipment, while invoking a throwaway policy a small percent of the time, thereby avoiding the need to purchase two pieces. In this way, a composite maintenance policy arises naturally and may be more cost effective than either a pure throwaway policy or pure test and repair policy.

Because of the complexity of the situation, the optimization model is developed progressively. The simplest case consisting of a single component system requiring only one special piece of equipment is first derived. The model is then generalized to handle N components sharing one type of repair equipment, trained technician, or special facility. The most general case permitting the system to have N components sharing L pieces of equipment, personnel, or facilities is developed last. The thesis of this article is that synergistic benefits can occur when the maintenance policies of a system's components are optimized relative to one another.

INTRODUCTION. Economics analysis is a comparative method to assist one in making an optimal selection. In the simplest case, one is confronted with making one and only one of several possible choices. For example, a business wishes to purchase a truck from among five possible commercially available trucks. The economics analysis permits selecting only one of the five possible trucks, because one cannot buy a composite truck made out of the best components and features of the five candidates. An entirely different situation may exist relative to logistics support alternatives, because many times one can employ a composite of the alternatives. To illustrate this point, suppose one wishes to decide whether to contract maintenance out or perform it in house. Furthermore, suppose the business has a vacant building, which could be used to handle one half of the expected volume of maintenance actions. Perhaps, a maintenance contractor can perform the repairs cheaper, but requires rent for using its facilities. Naturally, a tradeoff exists between doing the repairs more expensively in house saving facilities costs versus contracting the repairs out more cheaply, while having to pay a facilities rental fee. Of course, if the contractor agreed to not charge a facilities rental fee in return for using the business's vacant building, the problem might be settled by a simple agreement. However, such an agreement may not be possible for a variety of reasons, such as, costly relocation of trained personnel and complex machinery or unbearable time delays in setting up a new maintenance facility. Hence, an optimal solution might be found in a composite action, where one half of the maintenance is contracted, while the other half is performed in house using the available vacant building. As another similar example, suppose that 1.1 technicians are required to handle the expected volume of failed electronic components. Rather than hire two technicians, it may be optimal to hire one and employ a throwaway policy a fraction of the time.

In general, unused capacity, whether it be a building, trained technicians, or maintenance equipment, may force one to consider taking a composite action, rather than opting for one simple action. The objective of optimization should be to find the best composite action. Unfortunately, too often managers react in a compartmentalized thinking mode, where only one simple alternative can be thought possible at a time.

OPTIMIZATION OF A COMPOSITE MAINTENANCE POLICY. In the simplest case, where only two pure alternatives exist, the situation might be expressed as a mathematical programming optimization. The goal of the optimization would be to find the optimal fraction of times m1 to do a pure policy P1 and m2 to do a pure policy P2, where m1+m2=1. Some costs may be assumed to be proportional to a function of the mi (i=1,2), while others may be regarded as simply fixed overhead costs independent of m1 or m2 for 0<m1,m2<1. These considerations give rise naturally to formulating the optimization as a mathematical program. This simple case is formulated after first defining symbols.

Let fi (i=1,2) be the total costs to perform maintenance under policy Pi which are proportional to mi. Let Bi be a fixed cost per unit for an item i of required repair equipment, technician, or other similar item having an integral requirement associated with invoking policy Pi. The total cost of such an item required to support the system, when invoking policy Pi, is multiplied by a function hi dependent on the total required demand t and an integral number M. The integer M may be viewed as the number of repair equipment pieces not bought due to invoking other maintenance policies, such as throwaway, a part of the time. Ci is the total indirect cost associated with doing policy Pi, that is independent of t, mi, and M. For example, an indirect expense such as maintaining laboratory facilities may be independent of both work volume and the fractional time a policy Pi is employed. If policy Pi is not invoked, then Ci is zero. Finally, d is the fleet size and n(j) is the fractional number of a type of equipment, technician, or facility j required to support a pure repair policy for one system for some given time unit period.

Employing the described symbols, a mathematical program is devised for finding the optimal composite policy for a very simple, but representative case. For visualization, let us assume that policy P1 is to test and repair a defective item, while P2 is a throwaway policy. Only the two policies are considered for now. A throwaway policy simply means that a defective component is removed, discarded, and replaced by a new component. Also, it is assumed that the system for which an optimal maintenance concept is to be found has exactly one component requiring only one type of repair/test equipment. The notation $[\![m1]\!]$ means the greatest integer in m1. e.g. $[\![2.2]\!]=2$.

(A) MATHEMATICAL PROGRAM FOR ONE COMPONENT REQUIRING ONE TYPE OF EQUIPMENT.

minimize $g(m1,m2,M)=m1f1+m2f2+h1(t,M)B1+h2(t,M)B2+C1+C2$ for $0<m1,m2<1$
$g(1,0,0)=f1+h1(t,0)B1+C1$, and $g(0,1,h1(t,0))=f2+h2(t,h1(t,0))B2+C2$

subject to:
(1) $m1+m2=1$, m1, m2 are real variables, $0<m1,m2<1$
(2) $n(j)d-t\leq 0$, t is real
(3) $n(j)dm1-h1(t,M)\leq 0$, M is an integer variable to be optimized
(4) $0\leq M\leq h1(t,0)$

The objective function g may alternatively be expressed in one formula as

$$g(m1,m2,M)=m1f1+m2f2+(1-[\![1-m1]\!])(h1(t,M)B1+C1)+(1-[\![m1]\!])(h2(t,M)B2+C2).$$

Next, it is shown that for an optimal choice of $0<m1,m2<1$, and M, either the functions $hi(t,M)$ $(i=1,2)$ evaluated at (t,M) are both zero or one is negative for some t, while the other is positive. Suppose $g(m1,m2,M)$ is assumed optimal for $0<m1,m2<1$. Because C1 and C2 are independent constants greater than or equal to zero, without loss of generality we may assume $r(m1,m2,M)=g(m1,m2,M)-C1-C2$ is also minimized. The assumed optimization of a composite policy implies

(a) $r(m1,m2,M)\leq f1+h1(t,M)B1$ and
(b) $r(m1,m2,M)\leq f2+h2(t,M)B2$.

The inequalities (a) and (b) are respectively equivalent to

(a') $h2(t,M)B2\leq(f1-f2)(1-m1)$
(b') $h1(t,M)B1\leq(f2-f1)m1$.

Either $f1-f2$ or $f2-f1$ is negative unless f1 is equal to f2. In case f1 is not equal to f2, we have that one of $h1(t,M)$ or $h2(t,M)$ is negative, because the costs B1,B2 of equipment is assumed greater than or equal to zero. In the case that f1 is equal to f2, then $h1(t,M)$ or $h2(t,M)$ might both be zero. If both f1 equals f2 and $h1(t,M)$ and $h2(t,M)$ are zero, then it follows that the best policy is P1, if $C1<C2$ and P2, if $C2<C1$. In the unlikely event that C1 is equal to C2, then either a pure P1 or P2 policy is optimal.

This last discussion proves that the formulation in [2] cannot give a composite optimal policy other than the unlikely case of C1 equal to C2, because it is not possible to have negative values in what corresponds to its h1 and h2 functions. The formulation found there omits the integer variable M, prohibiting a nontrivial optimized composite maintenance policy.

A simple manually computable example is given next.

EXAMPLE. $f1=1$, $f2=2$, $C1=C2=0$, $d=100$, $n(j)=1/45$.

P1: Repair requires special repair equipment costing B1 per piece. This policy assumes one repairs a failed component and reinstalls it.
P2: This policy assumes one discards a failed component and replaces it with a new one.

In this example, the system is assumed to have only one component. Only pure policies P1 and P2 or linear combinations of them are possible. The functions $h1(t,M)$ is assumed to be $\llbracket t+1\rrbracket-M$. $h2(t,M)$ is assumed to be zero for simplicity. In effect, the form of h1 and h2 in this example forces no special equipment to be required for the throwaway policy P2 and only integral numbers of repair equipment for the repair policy P1. Under these assumptions, we have the following mathematical program

minimize: $g(m1,m2,M)=2-m1+(\llbracket t+1\rrbracket-M)B1$, $g(0,1,h1(t,0))=2$, $g(1,0,0)=1+\llbracket t+1\rrbracket B1$

subject to: $m1+m2=1$, $20/9\leq t$, $0\leq M\leq\llbracket t+1\rrbracket$, and $20/9m1\leq\llbracket t+1\rrbracket-M$.

For simplicity assume t is 20/9. In effect, no safety margin is allowed, in case the workload is heavier than expected. $\llbracket t+1\rrbracket=3$ implies $M=1$ or $M=2$ for a split policy. For $M=1$ the last constraint is equivalent to $m1\leq.9$ and for $M=2$ the last constraint is equivalent to $m1\leq.45$. Because $g(m1,m2,M)$ will be minimized when m1 is maximal, we must have that either $m1=.90$ or $m1=.45$ for an optimal split policy, corresponding to whether M=1 or M=2. The next table shows how the optimal maintenance policy varies according to the value B1 of the repair equipment.

Optimal Policy Table for Example 1

B1	discard g(0,1,3) =2	pure repair g(1,0,0)= 1+3B1	split .45/.55 g(.45,.55,2)= 1.55+B1	split .90/.10 g(.90,.10,1)= 1.10+2B1	Optimal Policy
.05	2.00	**1.15	1.60	1.20	P1
.10	2.00	**1.30	1.65	**1.30	.9P1 or P1
.20	2.00	1.70	1.75	**1.50	.9P1
.33	2.00	2.00	1.88	**1.76	.9P1
.45	**2.00	2.35	**2.00	**2.00	.45P1, P2 or .9P1
.50	**2.00	2.50	2.05	2.10	P2

The optimal policy is completely sensitive to the cost of the repair equipment. It should be no surprise that as the cost of test equipment rises, the more likely it becomes that a 100% throwaway policy is optimal.

Under the simplified assumptions of (A) along with the additional assumptions that $h1(t,M)=[\![t+1]\!]-M$ and h2 does not depend on M, it is proven that an optimal choice of M must be one of the values 0, 1, $[\![t+1]\!]-1$ or $[\![t+1]\!]$. Assume $f1<f2$ and $0<m1,m2<1$. Setting $p=([\![t+1]\!]-M)/(n(j)d)$, from constraint (3) it follows that $m1\leq p$. To minimize g for any fixed M, m1 or m2 should be chosen equal to p, because in general g may be expressed as

$$g(m1,m2,M)=m1(f1-f2)+(\text{terms}\geq 0) \text{ or } g(m1,m2,M)=m2(f2-f1)+(\text{terms}\geq 0)$$

If $f1<f2$ then by choosing $m1=p$, m1 is as large as it can be, which in turn forces the term $m1(f1-f2)$ to assume its least negative value. For a split policy this means M must be minimized in this case. On the other hand, if f2 is assumed smaller than f1, then $g(m1,m2,M)$ is minimized by maximizing m2. It still remains to prove that M cannot optimally assume a strictly intermediate value for a split policy.

Suppose that M is optimally chosen satisfying $1<M<[\![t+1]\!]-1$ for $0<m1<1$. It is clear that g as a function of M is injective (one to one). Therefore, for any k not equal to M in the interval $(1,[\![t+1]\!]-1)$ we have $g(m1,m2,M)<g(m1,m2,k)$, because g is assumed minimal. This last inequality is equivalent to

$$(k-M)B1<(k-M)(f2-f1/(n(j)d))$$

setting $k=M-1$ and $k=M+1$ leads to a contradiction that the left hand side and right hand side of the inequality are both less than each other. Thus, for split policies, M is optimally selected as either 1 or $[\![t+1]\!]-1$, corresponding to the two types of composite policies possible. It is easy to construct cases when the optimal policy is purely repair or purely discard, corresponding to M being equal to 0 and $[\![t+1]\!]$, respectively.

This last proof can be extended to a much wider choice of h1 and h2 functions, since the properties of h1 and h2 employed are readily abstracted.

SHARED EQUIPMENT. In this section, the mathematical program formulation (A) is generalized to account for more than one component sharing the same type of equipment. Because what is optimal for each component individually may not be optimal for the whole system, complications arise. For example, if two components share the same type maintenance mechanic and one requires 1.5 manyears effort and the other component requires 1.5, then optimized separately to a pure repair policy both might require 2 mechanics, whereas taken together 3 is optimal. Sharing of equipment dictates that some optimum balance yielding least costs must exist between the maintenance policies for components using common equipment, technicians, or facilities.

Next is a generalization of the mathematical programming formulation (A) to include N components sharing the same repair equipment j. Maintenance policy Pk is repair for k=1 and discard for k=2.

(B) MATHEMATICAL PROGRAM FOR MANY COMPONENTS SHARING ONE TYPE EQUIPMENT.

$$\text{minimize: } G=\sum_{i=1}^{N}(m(i,1)f(i,1)+m(i,2)f(i,2)) +$$

$$\left(\left[\!\!\left[\sum_{i=0}^{N}(1-[\![1-m(i,1)]\!])hi1(t(i,1))\right]\!\!\right]-M(1)\right)B1 \quad +\sum_{i=1}^{N}(1-[\![1-m(i,1)]\!])C(i,1)$$

$$+\sum_{i=1}^{N}(1-[\![m(i,1)]\!])C(i,2) + \left(\left[\!\!\left[\sum_{i=0}^{N}(1-[\![m(i,1)]\!])hi2(t(i,2))\right]\!\!\right]-M(2)\right)B2$$

subject to: (1) $m(i,1)+m(i,2)=1$ $(i=1,2...N)$, $0 \le m(i,k) \le 1$ for $k=1,2$.

(2) $n(j)d-\sum_{i=1}^{N}t(i,j)\le 0$, $t(i,j)$ are real, $j=1,2$, $i=1,2...N$

(3) $\sum_{i=1}^{N}n(i,j)dm(i,k)-h(t(1,j),t(2,j)...t(N,j),M(j))\le 0$, $j,k=1,2$

(4) $0<M(j)<h(t(j,1),t(2,j)...t(N,j),0)$, $M(j)$ integral for $j=1,2$.

(5) $h0j(t(0,j))=0$, if $\sum_{i=1}^{N}(1-[\![1-m(i,k)]\!])hij(t(i,j))$ is an integer, otherwise one for $j,k=1,2$. $\quad m(0,k)=\sum_{i=1}^{N}m(i,k)/N$.

As before, n(j) is the fraction of one resource item j per time unit per system required for support. n(i,j) is the fraction of one piece of equipment per time unit per system required to support the ith component. For brevity we set

$$h(t1,t2,\ldots tN,M)=\left[\!\left[\sum_{i=0}^{N}(1-\left[\!\left[1\cdot m(i,1)\right]\!\right])hi1(ti)\right]\!\right]-M.$$

Next is an example of how the maintenance policies for components sharing the same repair equipment vary with the value B1. The previous example is extended to include a second component. In order to force the example to be manually computable, many simplifications are assumed. At present, no computer logistics model exists which can solve the most general mathematical program formulated in this article.

EXAMPLE 2. In form (B) set N=2, C(i,1)=0, C(i,2)=0, and B2=0. Assume that hil(ti) is ti for i=1,2...N. Note that in some situations it might be desirable to set hil(ti) equal to $[\![$ ti+1 $]\!]$ to force usage of integral units of equipment. Moreover, one might set hil(ti) equal to $[\![$ ti+1 $]\!]$+1 in order to force optimal integral numbers of an equipment along with a spare piece for the sake of redundancy. In addition, one component might require redundancy, while another might not. Some may require integral numbers of equipment while others do not. The form of the functions hil(ti) depend on the needs of the user.

For the sake of the example, let n(j)=1/10, d=101, n(1)=n(2)=1/20, f(1,1)=1, f(1,2)=1.5, f(2,1)=1, and f(2,2)=1.5. In essence, we assume that two identical components share the same piece of equipment. This means that an optimal policy for one must also be optimal for the other by symmetry. Making this assumption forces this sample problem to be manually computable.

Next let us assume that a composite policy is optimal. i.e. Some optimally selected values m(i,1) and m(i,2) satisfy 0<m(i,1),m(i,2)<1. Using the assumed values just stated and algebraic manipulation, one can state the example mathematical programming problem under the assumption that an optimal composite policy exists.

Objective function: G=3-m(1,1)+(11-M)B1

Constraint: m(1,1) $\leq$ (11-M)/10.1

M can assume values from 1 to 10 for a split policy. To minimize G we should maximize m(1,1) subject to the constraint depending on M above. It follows that m(1,1) is best chosen equal to (11-M)/10.1 for each choice of M. Therefore, we have G=3-(11-M)(B1-1/10.1). As one can see from this form of G, the cost of one piece of equipment is critical. If B1 is less than 1/10.1, then M should be chosen maximal to minimize G. i.e M is chosen equal to 10. If B1 is greater than 1/10.1, then M should be chosen as small as possible to minimize G. i.e M is chosen equal to 1. In case B1 is exactly equal to 1/10.1, then the choice of M is immaterial! This last situation is highly improbable, however. In fact, if one assumes that the cost B1 is a continuous random variable, then the probability of B1 being exactly equal to 1/10.1 is zero. All that remains is to consider the pure policy cases, when M=0 and M=11.

Assuming M=0 is essentially equivalent to permitting a total repair policy for every component, while assuming M=11 equates to a discard policy for every component. If M is assumed equal to zero, then m(i,1)=1 and m(i,2)=0 for i=1,2,...N. In this case, we have G=2+11B1. If M is assumed equal to 11, then it easily follows from the formulation (B) that G=3.

Using the preceding analysis, the next table indicates the optimal maintenance policies for the two identical components sharing the same repair equipment. The optimal policy for both components is shown to vary according to B1 the price of one piece of repair equipment.

Example 2
Optimal Policy Table

B1	M=0 G=2+11B1	M=11 G=3	Composite policies G=3-(11-M)(B1-1/10.1)	Optimal policy
.050	2.55	3.00	3.05	100 % repair
.070	2.77	3.00	3.03	"
.090	2.99	3.00	3.01	"
.099	3.00	3.00	3.00	all policies optimum
.100	3.10	3.00	2.99	repair 99 %
.200	4.20	3.00	1.99	"

SHARED RESOURCES BY MANY COMPONENTS ALLOWING MANY REPAIR POLICIES. This next and last formulation allows N components to share L types of personnel, equipment or facilities, while permitting R repair policies. It is the most general case considered in this article. It is a straightforward generalization of formulation (B). Synergism between components sharing the same resources is especially encompassed by this final formulation.

An obvious extension of the optimization is to generalize the formulation to include many variations in repair policies, such as what is done in [2] and [4]. However, the extension to cover variations in repair policies and multiply shared resources is more an exercise in keeping notation and indices straight, than developing any new modeling abstractions. The many variations in repair policies considered in [2] and [4] are tied to the multiechelon nature of the supply and maintenance structure of the Army. One could easily redesign the notation used in this article to emphasize a multiechelon supply and maintenance structure, if desired. However, without good reason to do so, changing notation to emphasize multiechelon characteristics only complicates the formulation without adding any new clarity. Therefore, multiechelon effects are not delineated.

In addition, no attempt is made to integrate the optimization of maintenance and provisioning, simultaneously. To accomplish this objective requires integrating two optimizations, the one of provisioning and the one formulated in this article for maintenance policies. The integration of the two optimizations is difficult. If done properly, one would have to optimize provisioning within the scheme of the overall maintenance policy optimization, since provisioning quantities depend heavily on the choice of maintenance policy, as well as failure rates. Likewise, the choice of maintenance policy depends on minimizing costs, such as provisioning. Therefore, the optimizations of maintenance policy and provisioning is symbiotic in nature. In [1] an optimal provisioning model is formulated, which could be employed in this manner. In [1] it is proven that one can optimize provisioning without having to formulate a mathematical program, as was done for maintenance policies. It is shown in [1] that the optimization of provisioning is independent of the choice of any reasonable objective function. Hence, no complex algorithmic computations are required when employing the formulas found in this article. In [2], an attempt is made to integrate the optimization of both maintenance policy and initial provisioning in a way that employs two separate mathematical programming optimizations for each of these factors employing complex algorithmic solutions, rather than applying the new research results found in [1], which obviates the requirement. Also, the mathematical program employed for optimizing stock in [2] does not allow considering the method of stock ordering, as in [1].

Next is the formulation of the maintenance policy optimization for L shared resources by N components having R repair policies and one discard policy. In this formulation, B(j) is the cost per unit for a resource item j, C(i,k) is the total overhead cost due to invoking repair policy k for component i, and hi,j is a function dependent on the maximum possible required demand t(i,j) for resource j by component i. M(j) is analogous to M in (B).

(C) MATHEMATICAL PROGRAM FORMULATION FOR COMPONENTS SHARING COMMON RESOURCES, PERMITTING MORE THAN ONE REPAIR POLICY.

minimize:

$$G=\sum_{i=1}^{N}\sum_{k=0}^{R} m(i,k)f(i,k)+\sum_{j=1}^{L}\sum_{k=0}^{R}\left(\left[\!\!\left[\sum_{i=0}^{N}\left(1-[\![1-m(i,k)]\!]\right)h_{i,j}(t(i,j))\right]\!\!\right]-M(j)\right)B(j)$$

$$+\sum_{k=0}^{R}\sum_{i=1}^{N}\left(1-[\![1-m(i,k)]\!]\right)C(i,k)$$

subject to:

(1) $\sum_{k=0}^{R} m(i,k)=1$ for $i=1,2\ldots N$, $0\le m(i,k)\le 1$, $m(i,0)$ is the fraction of times that the discard policy is invoked. $m(i,k)$ are to be chosen optimally.

(2) $n(j)d-\sum_{i=1}^{N} t(i,j)\le 0$ for $j=1,2\ldots L$

(3) $\sum_{i=1}^{N} n(i,j)dm(i,k) - h(t(1,j),t(2,j)\ldots t(N,j),M(j))\le 0$ for $k=0,1\ldots R$

and $j=1,2\ldots L$

(4) $0\le M(j) < h(t(1,j),t(2,j),\ldots t(N,j),0)$ for $j=1,2,\ldots L$. $M(j)$ is an integer variable to be chosen optimally.

(5) $m(0,k)=\sum_{i=1}^{N} m(i,k)/N$ for $k=0,1\ldots R$.

Note that for convenience one can consider k=0 as the discard policy P0.

$$(6)\quad h0j(t(0,j))=0,\ \text{if}\ \sum_{i=1}^{N}(1-\left[\left[1-m(i,k)\right]\right])hi,j((t(i,j))\ \text{is a whole integer,}$$

otherwise h0j(t(0,j))=1.

Observe that the functions h are defined analogous to the formulation in [B] for h and are given for j=1,2...L as

$$h(t(1,j),t(2,j),..t(N,j),M(j))=\sum_{k=0}^{R}\left[\left[\sum_{i=0}^{N}(1-\left[\left[1-m(i,k)\right]\right])hij(t(i,j))\right]\right]-M(j).$$

One should notice the great flexibility yielded by permitting the hi,j to be any function appropriate to the user's needs.

CONCLUSION: The intent of this article is to emphasize the importance of optimizing maintenance planning. The US Armed Forces have recognized the importance of maintenance planning by institutionalizing the Military Standard 1390, which gives an outline for performing level of repair analysis on Air Force, Navy, and Marine systems. At present, the Army has a growing, active Level of Repair Analysis (LORA) program guided by its Logistics Support Analysis Military Standard 1388-1A. To emphasize the need for LORA, the US Army Materiel Command (AMC) has published a regulation AR 700-27 giving detailed policy and guidance for performing LORA. Proponents for the AMC LORA Program are in process of negotiating a revised version of the Military Standard 1390, which will incorporate US Army requirements for performing LORA.

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Computer Simulation of Manufacturing Systems

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Abstract

The use of computer simulation in modeling manufacturing entities is illustrated via a GPSS/H model of a flow line comprised of metal cutting machinery. Watervliet Arsenal manufactures large bore cannon components which are subsequently assembled and integrated into larger weapon systems. The model consists of four machines which produce five different cannon conponents. A modular program structure allows for m-machines and n-components in the model without major changes in the code. As such, this model may be modified for use with similar manufacturing systems.

Simulation models can and should play an important role in developing criteria for system design and performance, since multiple scenarios may be evaluated within short periods of time. Although the model presented here focuses on a manufacturing system, the techniques used may be extended to include military, business, and computer systems.

1. Introduction

Global competition within the manufacturing arena compels managers to seek out means of increasing productivity while maintaining product quality. Computer simulation is increasingly used as a tool to help achieve this goal. Simulation models allow decision-makers to assess system behavior without disrupting the system. Information garnered through a typical simulation study includes estimation of system throughput and utilization, the identification of system bottlenecks, and measures of system performance.

The model presented is coded in GPSS/H; a discrete event simulation language where transactions are the basic units of traffic (e.g., parts moving through a flow line). Each transaction has numeric properties associated with it ; the two most important being priority level and the parameter set. Priority levels range from 0 to 127; from lowest to highest priority, respectively. Higher priority transactions take precedence over lower priority transactions. In addition, each transaction may have assigned to it up to 100 parameters. This allows one to code models using indirect specification, vis-a-vis, direct specification of system entities.

To illustrate, consider a production line consisting of twenty-five different machines. Each part must be processed once on each machine. If direct specification of the machines is employed, then a series of three statements must be coded into the model for each machine, resulting in a total of seventy-five statements. Those statements cause a machine to be captured, a part to be processed, and the machine to be released. Indirect specification allows for those statements to be used only once. Each part is assigned to a machine using one of the transaction's parameter values to identify the required machine. In contrast to direct specification of machines, indirect specification requires only three statements to represent all twenty-five machines.

Transactions (parts) enter the model via GENERATE blocks and are tagged with a set of parameter values which keep track of variables such as the current operation, the type of machine required to perform that operation, and the time allowed to complete the operation. Queue statistics are generated using the QUEUE block and machines are modelled with the ENTER block via indirect specification. Queue and server statistics are compiled automatically and printed as part of the standard GPSS/H output.

2. Description of the Model

The model represents a system consisting of four machine tools (one additional machine of each type is available if needed) which process five different types of cannon components. For demonstration purposes, a fictitious model design was used. The machine tools are modelled as storages (a storage is created by using the ENTER block and may be any type of server). Associated with each storage is a queue; that is, waiting line at the machine site. Queues and storages are numbered one through four. The numbers correspond with machines which, respectively, drill, mill, grind, and broach.

Part processing times are uniformly distributed (based upon production time standards). Parts are assigned to machines according to priority class and are rank-ordered by operation number. Each operation is completed sequentially until processing is completed, or until the production period ends. The model possesses the following characteristics (all of which may be varied if desired):

a. Production equipment is available for forty hours per week.

b. Time units are minutes.

c. Part introduction rate is uniformly distributed.

d. Weekly production quantities are 20, 15, 10, 5, and 10 for BLK1, BLK2, RNG1, RNG2, and RNG3 respectively.

e. All processed parts pass inspection.

f. Part processing is prioritized according to importance relative to readiness.

g. Intermachine transit time is equal to zero.

h. Machine tools experience no downtime during production periods.

A requirement exists to produce two types of breech blocks (BLK1 and BLK2) and three types of breech rings (RNG1, RNG2, and RNG3). Those components, along with a description of the operations and production times are listed in Table 1. A part enters the system and queues at the required machine. If the machine is idle, the first part in the queue is processed by that machine. Otherwise, the part must wait until the machine is free. Processing of all parts progresses in this fashion until the work week ends. As parts are finished, their numbers are accumulated and tabulated as weekly production quantities. The model results will be used to determine whether weekly production quantities can be met utilizing the existing equipment.

Part Type	Operation	Mean Time
BLK1	Drilling	22
	Milling	15
BLK2	Grinding	22
	Broaching	16
	Milling	20
RNG1	Grinding	49
	Broaching	160
RNG2	Grinding	18
	Broaching	60
	Broaching	75
	Milling	135
RNG3	Grinding	52
	Milling	300

Table 1 - Processing Times (Minutes)

3. Simulation Results

Output from the four simulation runs is given in Table 2. Definitions of the column headings are:

a. Relative Clock - meaningful only when the BRESET block or RESET control statement is used (see Schriber, 1974). Otherwise, has the same value as the absolute clock.

b. Absolute Clock - the elapsed simulated time from the start of the simulation.

c. Non-zero Fullword Savevalues - the total number of parts produced at the time the simulation ends.

d. Queue - a list of the waiting lines; identified by machine number.

e. Maximum Contents - the greatest number of parts in line awaiting processing.

f. Average Contents - the average number of parts in the queue during simulation.

g. Total Entries - the total number of parts which entered the queue during the simulation.

h. Zero Entries - the total number of parts which experienced zero waiting time in the queue.

i. Percent Zeros - the zero entries value divided by the total entries value.

j. Average Time/Unit -the average amount of time that a part waited in queue during simulation.

k. $Average Time/Unit - the average amount of time that a part waited in queue during simulation excluding the zero entries.

l. Current Contents - the number of parts left in queue at the end of the simulation.

j. Storage - listing of the machines; identified by number (1 - drill, 2 - mill, 3 - grinder, and 4 - broaching machine).

k. Avg-Util-During - Total Time is the fraction of the total simulated time that the machine was busy. Avail Time is the fraction of the total simulated time that the machine is available. Unavl Time is the fraction of the total simulated time that the machine is captured by a part while it is in a disabled state.

l. Entries - the total number of parts that visited the machine.

m. Average Time/Unit - the average amount of time that the machine was being used.

n. Current Status - the machine is either AVAIL (available) or UNAVAIL (unavailable).

o. Percent Avail - the fraction of total simulated time that the machine was available.

p. Capacity - the number of machines of given type.

q. Average Contents - the average time a part is being processed per part.

r. Current Contents - the number of machines of given type in use at the end of the simulation.

s. Maximum Contents - the number of machines of given type ever used during the simulation.

Four versions of the model were executed, each for 2,400 minutes (40 hours) of simulated time. The models differ only in the number of machines used to process the parts. The number of machines in the original model was systematically increased based upon preceding simulation results (refer to Table 2 - savevalue & average utilization listings and Table 3). The output quantities for a single run of each model are summarized in Table 4. Note that weekly production requirements are not met with the machine configurations considered.

Models 3 and 4 were selected for further analysis based upon simulation results (Table 2). Ten replications of each model were run. Ninety-five percent confidence limits for weekly part output were calculated using the information contained in Tables 5 and 6, and are listed in Table 7.

The results of the simulation indicate that the weekly production requirements will not be met using the available equipment (refer to Table 7). Reference to Table 4 - Model 4 shows that, with seven machines, queue sizes are small and average waiting times are low. Also, the average machine utilization for all machines ranges from 41.5% to 52.0%. This leads one to suspect that weekly production schedules are not being met due to causes other than machine utilization. Recall that parts are introduced into the system stochastically. When parts are introduced deterministically (using the mean value from the original uniform distribution), weekly production quantities consistently meet requirements. Prompted by this, the process which supplies parts to the flow line was examined. It was found that the rate of parts introduced into the flow line could be increased. As a result, Model 4 was modified so that part entry into the system occurred at a higher rate.

Model 4 was executed once more (replicated ten times), with increased part introduction rates), resulting in the following:

a. Average machine utilization for all machines ranged from 48.9% to 66.4%.

b. Maximum queue sizes at each machine never exceeded two.

c. The ninety-five percent confidence limits for weekly part output was: BLK1 - [23.3, 24.7], BLK2 - [19.7, 20.7], RNG1 - [11.3, 12.9], RNG2 - [5.7, 6.5], and RNG3 - [11.3, 12.7].

It has been shown that by increasing part entry rate into the system, while utilizing one drill and two each of grinders, mills, and broaching machines, that the mean weekly output for each part will meet or exceed the weekly requirements (this is evidenced by the ninety-five percent confidence limits for the mean weekly outputs listed in c. above).

4. Summary

Computer simulation is an extremely powerful tool that is well suited for modeling manufacturing systems. The production capacity of a flow line was used to illustrate the utility of this technique. Multiple versions of the base model (Model 1) were compared in order to determine the number of machine tools needed to meet production requirements. In addition, it was determined that part introduction rate was a limiting factor due to the variability associated with part entry into the system. An increase in the rate that parts entered the system, combined with the machine configuation of Model 4, resulted in weekly output that meets the given requirements, with a high degree of certainty.

Modeling has proven itself a valuable tool at Watervliet Arsenal, where it has been used for a number of years in addressing system issues ranging from capacity analysis of a flow line to bottleneck analysis of a flexible manufacturing system. Current applications include capacity analysis of a proposed tool management system, staffing levels required to support a flexible manufacturing system, and a performance model for a proposed implementation of block tooling in a cannon tube machining flow line.

RELATIVE CLOCK: 2400 ABSOLUTE CLOCK: 2400

NON-ZERO FULLWORD SAVEVALUES <NAME : VALUE>

BLK1: 18 BLK2: 13 RNG1: 9 RNG2: 5

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
1	1	0.000	20	20	100.0	0.000	0.000	0
2	13	5.616	49	2	4.1	275.063	286.767	12
3	3	1.305	42	1	2.4	74.590	76.409	1
4	3	0.992	35	8	22.9	68.025	88.180	1

	----AVG-UTIL-DURING----										
STORAGE	TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
1	0.411			20	49.270	AVAIL	100.0	1	0.411	0	1
2	0.960			37	62.259	AVAIL	100.0	1	0.960	1	1
3	1.000			41	58.537	AVAIL	100.0	1	1.000	1	1
4	0.949			34	66.994	AVAIL	100.0	1	0.949	1	1

MODEL 1 RESULTS

RELATIVE CLOCK: 2400 ABSOLUTE CLOCK: 2400

NON-ZERO FULLWORD SAVEVALUES <NAME : VALUE>

BLK1: 18 BLK2: 14 RNG1: 9 RNG2: 5 RNG3: 3

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
1	1	0.000	21	21	100.0	0.000	0.000	0
2	10	3.782	50	4	8.0	181.529	197.314	9
3	2	0.117	41	33	80.5	6.864	35.176	0
4	3	0.937	35	9	25.7	64.246	86.484	0

	----AVG-UTIL-DURING----										
STORAGE	TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
1	0.402			21	45.943	AVAIL	100.0	1	0.402	1	1
2	0.963			41	56.347	AVAIL	100.0	1	0.963	1	1
3	0.499			41	58.440	AVAIL	100.0	2	0.998	1	2
4	0.977			35	66.981	AVAIL	100.0	1	0.977	1	1

MODEL 2 RESULTS

Table 2

RELATIVE CLOCK: 2400 ABSOLUTE CLOCK: 2400

NON-ZERO FULLWORD SAVEVALUES <NAME : VALUE>

BLK1: 20 BLK2: 14 RNG1: 10 RNG2: 5 RNG3: 10

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
1	1	0.000	21	21	100.0	0.000	0.000	0
2	2	0.024	51	48	94.1	1.150	19.545	9
3	2	0.076	42	34	81.0	4.342	22.797	0
4	2	0.890	35	10	28.6	61.054	85.476	0

	----AVG-UTIL-DURING----										
STORAGE	TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
1	0.458			21	52.323	AVAIL	100.0	1	0.458	0	1
2	0.501			51	47.108	AVAIL	100.0	2	1.002	2	2
3	0.519			42	59.279	AVAIL	100.0	2	1.038	2	2
4	0.969			35	66.479	AVAIL	100.0	1	0.969	0	1

MODEL 3 RESULTS

RELATIVE CLOCK: 2400 ABSOLUTE CLOCK: 2400

NON-ZERO FULLWORD SAVEVALUES <NAME : VALUE>

BLK1: 19 BLK2: 15 RNG1: 10 RNG2: 5 RNG3: 10

QUEUE	MAXIMUM CONTENTS	AVERAGE CONTENTS	TOTAL ENTRIES	ZERO ENTRIES	PERCENT ZEROS	AVERAGE TIME/UNIT	$AVERAGE TIME/UNIT	CURRENT CONTENTS
1	1	0.000	20	20	100.0	0.000	0.000	0
2	1	0.043	50	40	80.0	2.071	10.353	0
3	2	0.152	42	33	78.6	8.668	40.451	0
4	1	0.021	35	33	94.3	1.452	25.417	0

	----AVG-UTIL-DURING----										
STORAGE	TOTAL TIME	AVAIL TIME	UNAVL TIME	ENTRIES	AVERAGE TIME/UNIT	CURRENT STATUS	PERCENT AVAIL	CAPACITY	AVERAGE CONTENTS	CURRENT CONTENTS	MAXIMUM CONTENTS
1	0.415			20	49.763	AVAIL	100.0	1	0.415	0	1
2	0.520			50	49.889	AVAIL	100.0	2	1.040	1	2
3	0.502			42	57.363	AVAIL	100.0	2	1.004	2	2
4	0.486			35	66.669	AVAIL	100.0	2	0.972	0	2

MODEL 4 RESULTS

Table 2 - Con't

MODEL	DRILL	MILL	GRIND	BROACH	TOTAL
1	1	1	1	1	4
2	1	1	2	1	5
3	1	2	2	1	6
4	1	2	2	2	7

Table 3 - Machine Quantities by Model

MODEL	BLK1	BLK2	RNG1	RNG2	RNG3
1	18	13	9	5	0
2	18	14	9	5	3
3	20	14	10	5	10
4	19	15	10	5	10

Table 4 - Output Quantities by Model & Component

	BLK1	BLK2	RNG1	RNG2	RNG3
	20	14	10	5	10
	20	15	10	5	10
	20	15	10	5	10
	20	15	11	5	9
	19	15	9	5	11
	21	14	11	4	10
	20	16	9	5	9
	20	14	10	6	10
	20	16	9	5	11
	20	15	11	5	11
MEAN:	*20.0*	*14.9*	*10.0*	*5.0*	*9.8*
STD. DEV:	*0.61*	*0.50*	*0.72*	*0.39*	*0.61*

Table 5 - MODEL 3 Replicates

	BLK1	BLK2	RNG1	RNG2	RNG3
	20	14	10	5	10
	20	15	10	5	10
	20	15	9	5	11
	19	15	9	5	11
	21	14	11	4	10
	20	16	9	5	9
	20	15	9	5	10
	20	15	11	5	9
	20	14	10	6	10
	20	16	9	5	10
MEAN:	*20.0*	*14.9*	*9.7*	*5.0*	*10.0*
STD. DEV:	*0.61*	*0.72*	*0.79*	*0.39*	*0.72*

Table 6 - MODEL 4 Replicates

PART	MODEL 3	MODEL 4
BLK1	[19.3, 20.7]	[19.3, 20.7]
BLK2	[14.4, 15.4]	[14.1, 15.7]
RNG1	[9.2, 10.8]	[8.8, 10.6]
RNG2	[4.6, 5.4]	[4.6, 5.4]
RNG3	[9.1, 10.5]	[9.2, 10.8]

Table 7 - 95% Confidence Limits for Part Output

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#217

TITLE: Vector in Command - G3 (VIC-G3)

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ABSTRACT:

Scenario generation for combat simulations is very manpower intensive and time consuming. Army simulations, specifically VIC, require maneuver planning for a multitude of units keeping in mind command and control relationships and the execution of appropriate doctrine. Current procedures involve the manual development of the scheme of maneuver and graphics inputs of movement traces for each and every unit. Due to the inability to foresee simulation results, several iterations of movement planning are required for a scenario to execute properly.

Addressing this problem, an automated movement planner has been developed to assist scenario developers by eliminating the requirement for manual input of maneuver routes. Implementing a logic structure which uses network analysis and utility theory in a hierarchical fashion, positioning and movement plans are generated which emulates the plans generated by military planners. Features of the system include top-down planning, appropriate use of terrain, and development of maneuver and fire plans consistent with the commander's intent for the scheme of maneuver. A graphics interface allows scenario developers the ability to review and update plans. This work is an application of AI and graphics to preprocessing simulation data. The research is on-going in TRAC and has a targeted implementation as part of the VIC graphics preprocessor.

USAREUR ORSA PROGRAM

LTC THOMAS C. WEGLEITNER

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OPERATIONS RESEARCH SYSTEMS ANALYSIS CELL

BACKGROUND

For military analysts, an integral part of their professional development includes periodic moves between various organizations. Moving provides a broadening experience and serves as a basis for applying professional judgment regarding the realism of modeling and analytical activities conducted by many organizations represented at the Army Operations Research Symposium. In contrast to the development pattern of military analysts, a civilian analyst might spend a career with an organization and never get closer to the system/organization he is trying to analyze than a short TDY visit. It is, in part, recognition of this lack of analyst's direct experience with the Army in the field that led to a recommendation in the "Review of Army Analysis" that Operations Research Cells be established in US Army Europe and 7th Army (USAREUR). (FOOTNOTE 1)

An MOU between CINCUSAREUR and VCSA was signed in 1980 (later revised in 1984) which defined the purpose, size and scope of an operations research program in USAREUR. In particular:

- The Deputy Undersecretary of the Army for Operations Research (DUSA (OR)) directs the program and convenes a selection panel each year to select analysts to serve a two year tour in Europe.

- MACOMs provide the analysts and pay their salaries.

- USAREUR provides the military cell chief, admin support, PCS costs, CPO support, TDY, and housing allowance.

MISSION

The mission of the program is threefold:

- Give high quality, responsive ORSA analytical support to the Command Groups of the various cells.

- Provide a meaningful professional development opportunity for participating analysts.

- Furnish a USAREUR analytical point of contact for CONUS agencies.

Guidance for the analysts comes from the DUSA (OR). First, analysts are expected to work on a variety of projects. Each study should be simple, but effective and have a duration of no longer than six months. Second, each analyst is expected to submit to the DUSA (OR) a "White Paper" robust in size, which displays analytical depth and is written on a subject valuable to USAREUR. Finally, analysts are expected to participate in a professional development program which expands their experience and horizons.

In summary, the ORSA Cells have the following essential tasks:

- Conduct operations research studies, evaluations or analyses in areas of interest to USAREUR.

- Provide advice and assistance to Command Groups and staff on applications of operations research techniques to projects and problems.

- Coordinate ORSA matters among higher, lower and adjacent commands.

- Serve as point of contact for the Army Studies Program (AR 5-5)

- Provide a professional development program for analysts which enhances ORSA expertise and broadens knowledge of US Army activities in Europe.

ORGANIZATION

Operations Research Cells are located in four areas of West Germany:

- HQ, USAREUR -- Heidelberg

- HQ, V Corps -- Frankfurt

- HQ, VII Corps -- Stuttgart

- HQ, 21st TAACOM -- Kaiserslautern

The USAREUR cell is the largest with one military chief (LTC), one admin, and seven analysts. The other cells have one military chief (LTC), one admin, and two analysts. The cells are part of the Command Group with the chief being rated by the Chief of Staff or Deputy Commander. Being part of the Command Group provides an opportunity for the cells to undertake a broad range of tasks without concentrating in the mission areas of a particular staff element. Additionally, the opportunity to work on various tasks means that the individuals selected for duty with the cells can come from a wide variety of backgrounds. (FOOTNOTE 2)

PARTICIPATION

Participation in the USAREUR ORSA program is voluntary. Each January DA solicits applicants from agencies CONUS wide. In March a selection board meets to choose from prospective candidates. Six are chosen: three for the USAREUR cell and one each for the other cells. Thus one half the analysts in Europe turn around each year.

General criteria for selection are:

- Analysts at CONUS commands/agencies are eligible.

- Analysts should be GS/GM 13-14. Consideration will be given for GS/GM 12 analysts possessing a high degree of specialized analytical experience. Analysts are selected at current grades and not promoted for duty with the cells.

- Analysts do not need to be in the GS-1515 job series. Selection is based on operations research background and other special analytic skills, eg. simulation, weapons systems or logistics.

- Tour of duty is two years with no extension possible.

- Each analyst will complete for publication at least one research project on a USAREUR issue.

- To apply analysts submit a current SF 171 and cover memorandum which addresses reasons for wanting to participate in the program.

- Analysts submit nominations through command channels.

- Commanders or agency heads must certify availability of the analysts.

Analysts selected remain on CONUS parent activity authorization documents with duty station in USAREUR. Parent activities pay salary and direct benefit costs. USAREUR pays annual cost of living allowance, PCS costs, POV shipment and foreign transfer costs.

STUDY EFFORTS

The study program for the cells is approved by the respective Chiefs of Staff. Requests for study efforts are generated externally by the staff/Command Group or internally by members of the cell. In contrast to methods of analysis at major CONUS organizations, there are no sophisticated computer models supporting tasks conducted in-theater and little computer support in the form of programmers. All cells do, however, have PC's. Analytical efforts in the cells generally consist of an individual or a team of two working a task with most discussions conducted outside the cell. This, again, contrasts with CONUS agencies where analysts work as part of teams on large study efforts. Another variation from CONUS is that most cell tasks represent short term requirements where a memorandum or briefing will document the study results. This use of memoranda or briefing charts differs from the widespread use of formal study reports at CONUS organizations. (FOOTNOTE 3)

The following are examples of types of projects undertaken by the cells:

- CINC's Force Analyzer: functional description for a computer system to analyze TPFDL data and give CINC current status on reinforcements.

- EJTR versus LJTR Economic Analysis: detailed cost analysis of increased HHG weight allowances for USAREUR personnel. Conclusions resulted in Europe going to an elective JTR system.

- CINC Initiative Tracking System: automated aid to track and give status on CINCUSAREUR projects.

- Theater Printing Operations: thorough analysis of all levels of printing in USAREUR to determine maximum production for minimum cost.

- Sampling Method for Inspections: methodology for chosing POMCUS equipment for periodic examinations.

- Student Projection Model: method for DOD Dependent Schools to estimate enrollment for the coming school year

- FY90 Grafenwoehr Training Schedule: schedule to satisfy battalion training needs of V and VII Corps.

- CINC's Trains: analytical examination of usage of CINCUSAREUR's trains and how to most cost effectively employ them.

- Housing Forecast Model: computer program to forecast family housing availability.

- Sponsorship Express Bus: analysis of transport methods from Rhein Main to communities for incoming PCS personnel. This analysis resulted in opening air travel direct to Nuernberg and Stuttgart.

- FORCECOMP Model: enhancements to CENTAG's Force Comparison model. Project done in coordination with TRAC, Ft. Leavenworth.

- Transport of M1/M2/M3: examine fielding plan for Heavy Equipment Transporters (HET) and determine most cost effective means to transport Abrams and BFV to training centers.

- EJTR for Single/Unaccompanied Soldiers: cost analysis of higher weight allowances for single and unaccompanied personnel who PCS to USAREUR.

- Army Study Program: survey of USAREUR staff for Army War College and Army Study Program (AR 5-5) projects.

- Housing Contractual Support: Analysis of USAREUR Housing Referral Offices to determine which functions could be contractually supported.

- USAREUR Role in LRRDAP: increase participation of CINCUSAREUR in LRRDAP process.

- CFE Database: system to maintain and retrieve data in support of CFE negotiations and implementation.

- Class I War Reserve Stocks: data gathering for Natick Labs and USAREUR DCSLOG to determine availability of Class I for wartime operations.

- Community Support Capability: computer model to assess adequacy troop and family support organizations in Europe.

- Management of Simulations in Europe: examine current simulation management in USAREUR and make recommendations for improvement.

PROFESSIONAL DEVELOPMENT

As part of the "bargain" with the analysts for coming to Europe, a thorough professional development program has been initiated. The purpose is to give the analyst a feeling for how the Army in the field operates and an appreciation of the German way of life. First, all analysts are classified as emergency essential civilians. They are expected to participate in alerts, field exercises. NBC training and weapons firing. Analysts are brought to the other cells for command briefings and discussions on how the other commands operate. Tours of battlefields, POMCUS sites, training areas, Berlin and the East German border are arranged. In addition, analysts receive training in German and spend a week at Haus Rissen to gain a further understanding of the German country, its people and politics. Taken all together.

the above programs provide a solid base for the analyst's understanding of the US Army in Europe and the German culture.

BOTTOM LINE

All things considered, the USAREUR ORSA program provides an opportunity for an analyst to learn first hand about the Army and also gives USAREUR first class ORSA support. The program is important to USAREUR: commanders and staff use it and, last but not least, returns an analyst who has "been there".

Footnotes 1 thru 3: Paraphrased from "A Tour of Duty with the USAREUR ORSA Cell", Joseph E. Koletar, Jr.

HQ USAREUR

OPERATIONS RESEARCH SYSTEMS ANALYSIS CELL

BRIEFING OUTLINE

- BACKGROUND
- MISSION
- ORGANIZATION
- PAST AND CURRENT PROJECTS

BACKGROUND

THE ORSA PROGRAM BEGAN IN 1980 AS A RESULT OF THE 1979 "REVIEW OF ARMY ANALYSIS" STUDY.

CINC/VCSA MOU PROVISIONS:

- HQDA AND CONUS/MACOM PROVIDE...........
  - SELECTION PANEL
  - CIVILIAN ANALYSTS (2 YEAR TOUR)
  - SALARY

- HQ USAREUR PROVIDES........
  - MILITARY ANALYST
  - ADMIN SUPPORT
  - FUNDING FOR PCS/TDY
  - HOUSING ALLOWANCE
  - CPO SUPPORT

MISSION

THE HQ, USAREUR ORSA CELL WAS ESTABLISHED TO PROVIDE:

- HIGH QUALITY, RESPONSIVE ORSA ANALYTICAL SUPPORT TO COMMAND GROUP, STAFF AND UMC.
- A MEANINGFUL PROFESSIONAL DEVELOPMENT OPPORTUNITY FOR PARTICIPATING ANALYSTS.
- ANALYTICAL POC TO CONUS AGENCIES.

DUSA (OR) GUIDANCE

- VARIETY OF PROJECTS
- KEEP IT SIMPLE, BUT EFFECTIVE
- 6-MONTH LIMIT
- WHITE PAPER REQUIREMENT
- PROFESSIONAL DEVELOPMENT

MISSION ESSENTIAL TASK LIST

- CONDUCT OPERATIONS RESEARCH STUDIES, EVALUATIONS OR ANALYSES ON PROBLEM AREAS AS DIRECTED BY THE COMMAND GROUP.
- PROVIDE ADVICE AND ASSISTANCE TO THE COMMAND GROUP, STAFF AND SUBORDINATE UNITS ON APPLICATIONS OF OPERATIONS RESEARCH TECHNIQUES TO PROJECTS AND PROBLEMS.
- COORDINATE ORSA MATTERS AMONG HIGHER, LOWER AND ADJACENT COMMANDS.

MISSION ESSENTIAL TASK LIST - CONT

- SERVE AS POINT OF CONTACT FOR THE ARMY STUDIES PROGRAM (AR 5-5 SERIES)

- PROVIDE A PROFESSIONAL DEVELOPMENT PROGRAM FOR ANALYSTS THAT DEVELOPS ORSA EXPERTISE AND BROADENS KNOWLEDGE OF US ARMY ACTIVITIES IN EUROPE

CELL LOCATIONS

HQ USAREUR - HEIDELBERG

HQ V CORPS - FRANKFURT

HQ VII CORPS - STUTTGART

21ST TAACOM - KAISERSLAUTERN

CELL STRUCTURE

USAREUR CELL	1 MILITARY CHIEF (LTC) 1 ADMIN 7 ANALYSTS
OTHER CELLS	1 MILITARY CHIEF (LTC) 1 ADMIN 2 ANALYSTS

SAMPLE OF CURRENT PROJECTS

PROPONENT	STUDY/PROJECT
CENTAG/CINC	FORCECOMP MODEL
CINC	TRANSPORT OF M1/M2/M3
COFS	EJTR FOR SINGLE/ UNACCOMPANIED SOLDIERS
ORSA	ARMY STUDY PROGRAM
ODCSENG	HOUSING CONTRACTUAL SPT
ORSA	USAREUR ROLE IN LRRDAP
ODCSOPS	CFE DATABASE
ODCSLOG	CLASS I WRS
ODCSPER	COMMUNITY SUPPORT CAPABILITY
ODCSOPS	MANAGEMENT OF SIMULATIONS IN EUROPE

SAMPLE OF COMPLETED PROJECTS

PROPONENT	STUDY/PROJECT
CINC	CINC'S FORCE ANALYZER
ODCSENG/COFS	EJTR VS LJTR ECON ANALYSIS
SGS	CINC INITITATIVE TRACKING
DCSIM/DCINC	THEATER PRINTING OPS
CEGE	SAMPLING METHOD FOR INSPECTIONS
DODDS	STUDENT PROJECTION MODEL
ODCSOPS	FY 90 GRAF/CMTC SCHEDULE
SGS	CINC'S TRAINS
ODCSENG	HOUSING FORECAST MODEL
21ST REPL BN	SYSTEMS ANALYSIS OF SPONSORSHIP EXPRESS BUS

PROFESSIONAL DEVELOPMENT

GERMAN CLASSES	WEAPONS FIRING
HAUS RISSEN	NBC TRAINING
COMPUTER CLASSES	REFORGER
UMC CMD BRIEFING	ABLE ARCHER
EUCOM CMD BRIEFING	WINTEX-CIMEX
CENTAG CMD BRIEFING	CRESTED EAGLE
BERLIN BDE	BORDER TOUR
WARRIOR PREPARATION CENTER	BATTLEFIELD TOURS
SHAPE TECHNICAL CENTER	POMCUS/TR STOCKS
INTERNATIONAL ORSA SYMPOSIUM	GRAFENWOEHR

BOTTOM LINE

- IMPORTANT PROGRAM TO USAREUR
- COMMANDERS/STAFF USE IT
- RETURNS ANALYST WHO HAS "BEEN THERE"

PEACETIME REPLACEMENT AND CRASH DAMAGE FACTORS

FOR ARMY AIRCRAFT

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INTRODUCTION

Army aircraft accidents are among the highest concerns of Army management. The army invests significant amounts of money into training aviators. This money is lost when there is a mishap that involves fatalities to aviators. The Worldwide Aviation Logistics Conference (WALC) meets annually at the U. S. Army Aviation Systems Command. It uses Pe--etime Replacement and Crash Damage Factors to help foresee trends in acciden' tes for a proposed flying hour program. The Peacetime Replacement Factor ' RF) relates flying hours to Class A accident rates for a particular aircra ,. The Crash Damage (CD) factor relates flying hours to Class B accident rates for a particular aircraft. Flying hours are expressed on a per 100,000 basis. An annual update is made to these factors for the WALC conference. Army aircraft mishaps are defined by AR 385-40 with specific dollar thresholds. At this point it would be helpful to define the classes of accidents and their thresholds. The thresholds shown here were under revision upward at the time this paper was written to account for the increased expense of parts on the newer aircraft.

ACCIDENT CLASS	THRESHOLDS
A	$500,000 or greater or fatality
B	$100,000 up to less than $500,000
C	$10,000 up to less than $100,000
D	$1,000 up to less than $1 ,000
E	losses less than $1,000

The data used in this study came from the Army Safety Center data base at Ft. Rucker Alabama. The Safety Center maintains data on flying hours and accident occurrences. A data base has been set up in the Directorate of Systems and Cost Analysis at AVSCOM that contains Class A and Class B accident occurences along with associated flying hours for most of the Army aircraft systems.

This data base is contained in a Statistical Analysis System (SAS) program file residing on the Midwest Scientific and Engineering Computer System at AVSCOM. This program file also contains the program statements necessary to perform the regression analysis which generates the PTRF and CD factors for the WALC.
This data base currently extends from 1974 through 1988 and will be added to each year to update the factor for the annual WALC conference.

SAS Methodology

Linear Curve Fitting Procedures

SAS programming language provides a user friendly set of commands which allow the analyst to apply commonly used statistical techniques to a data base. Within these commands, the user can specify procedures to:

1. Perform a linear regression analysis

2. Perform a non-linear regression analysis

3. Plot raw data and regression points

4. Generate a linear equation of the form Y = a + bx

5. Generate a non-linear equation curve

6. Perform goodness of fit tests

7. Generate descriptive statistics

General Linear Models (GLM) Procedure

The GLM procedure will fit a straight line to the user's data by the method of least squares. It has proven successful for the generation of PTRF and CD factors for most aircraft systems. GLM provides the user with a straight line equation of the form:

$$Y = a + b(x) \qquad (1)$$

The independent variable (Y) in equation 1 is the cumulative number of accidents (Class A or Class B). The constant (a) is the y axis intercept of equation 1. The variable (b) is the slope of equation 1. The dependent variable (x) is the cumulative number of flight hours expressed per 100,000. Flight hours are not the only data that could have been used as the independent variable. They are recognized as a driver of accident rates. Also, flight hour data is readily available.

Non-Linear (NLIN) Models Procedure

The NLIN procedure is used where there is a poor fit with equation 1. A polynomial equation which has given improved results compared to equation 1 is:

$$Y = B0(x)^3 - B1(x)^2 + B2(x) - B3 \qquad (2)$$

The UH-1 aircraft was modeled using equation 2 and the NLIN procedure. Cumulative class B accidents were used along with cumulative flying hours as input to the NLIN procedure. Figure 1 illustrates result of this procedure. The (B) symbols represent model generated data points. The curve reaches a maximum at approximately 3 accidents. The square symbols represent model generated data. Between the low and high points on the curve is a point where the curve changes from an increasing slope to a decreasing slope. This is the point that is used to calculate the CD factor. Its value is found by taking the second derivative of the polynomial equation generated by the NLIN procedure, setting it equal to zero and solving for (H).

The following is an example of how this is accomplished for the UH-1:

1. Start with the equation of the curve generated by the SAS procedure NLIN.

$$B = -.0279(H)^3 + .271(H)^2 + .0295(H) -.751 \qquad (3)$$

$$\frac{dB}{dH} = -.0837(H)^2 +.542(H) + .0295 \qquad (4)$$

$$\frac{d^2B}{dH^2} = -.1647(H) + .542 \qquad (5)$$

2. Set equation 5 equal to zero and solve for the value of H:

$$-.1647(H) +.542 = 0$$

$$H = 3.238$$

3. Substitute the value of H = 3.238 into equation 3.

$$B = -.0279(3.238)^3+.271(3.238)^2+.0295(3.238)-.751$$

$$= 1.24$$

4. The slope corresponding to the point at which the curve changes slope (point of inflection) is:

$$B/H = 1.24/3.238 = .38$$

The value of .38 becomes the Crash Damage (CD) factor for the UH-1 aircraft. This value gives an indication of the trend in Class B accidents. Four other systems were modeled in a like manner. These systems and their generated equations are shown in Table 1.

TABLE 1
NON-LINEAR REGRESSION MODELS

AIRCRAFT	MODEL	R^2
UH-1H	$B = -.00004(H)^3+.008(H)^2+.08375(H)+4.311$	.996
OH-6A	$B = -.1218(H)^3+.856(H)^2-1.332(H)+.449$	.931
OH-58	$B = -.00013(H)^3+.0089(H)^2-.1028(H)+.2199$	.959
TH-55	$A = .07974(H)^3-1.715(H)^2+11.776(H)+5.619$	.9995
UH-1	$B = -.0279(H)^3+.271(H)^2+.0295(H)-.751$	.960

Use of the non-linear technique resulted in an improvement in correlation coefficient. R^2 increased from 8.5% to 22.4% as shown in Table 2 when using the non-linear model in place of the linear equation.

TABLE 2

LINEAR / NON-LINEAR FACTOR COMPARISON

AIRCRAFT	FACTOR		R SQUARE		IMPROVEMENT
	LINEAR	NON-LINEAR	LINEAR	NON-LINEAR	
UH-1 (CD)	.572	.383	.784	.960	22.4%
UH-1H (CD)	.491	.512	.902	.996	10.4%
OH-6 (CD)	.368	.417	.761	.931	22.3%
OH-58 (CD)	.072	.460	.884	.959	8.5%
TH-55(PTRF)	1.305	4.36	.595	.999	68.0%

LINEAR MODEL RESULTS

The following systems displayed good results with the General Linear Models (GLM) procedure. Table 3 displays these systems along with their CD/PTRF factors and R^2 coefficients.

TABLE 3

LINEAR MODEL RESULTS

Aircraft	Accident Class	Factor PTRF/CD	R^2
UH-1	A	4.16	.94
UH-1H	A	.1.97	.99
OH-6A	A	2.34	.966
OH-58A	A	3.44	.992
CH-47	A	4.24	.986
CH-47	B	4.22	.978
UH-60	A	5.13	.96
UH-60	B	1.79	.93
CH-54	A	3.87	.86

C-12	B	.558	.86
T-42	A	2.55	.897
U-8	A	2.74	.90
U-21	A	1.1	.94
OV-1	A	7.9	.98
AH-1	A	4.0	.99
AH-1	B	3.1	.94

DIFFICULT SYSTEMS TO MODEL

Some systems did not fit the linear or non-linear models well. An example is the CH-54. Class B accidents for this system have shown little change for several years. This makes it difficult to ascertain any trends from the data. The CH-54 has also shown a low number of flying hours; the total fleet has only flown around 8,000 hours in recent years. It is likely that this system will not experience much change to its data base due to the age of the model and its reduced mission for the army. In this case an algabraic relationship was used to develop a crash damage (CD) factor.

NON-LINEAR CURVE FITTING

The UH-1H data and fitted polynomial curve are displayed in Figure 2. Also labeled are the number of class B accidents and flying hours for each year in the aircraft data base. This plotted curve is an exponentially smoothed representation of equation 2. As in all polynomial curves, there are local maximum and minimum points on this curve. In the case of a cubic equation such as equation 2, there is a maximum and a minimum point falling somewhere on the curve. In the equation for the UH-1 aircraft, the minimum point falls somewhere to the left of the y axis and is not of interest. The maximum point falls where the cumulative flight hours are approximately equal to 1,000,000 and cumulative class B accidents are approximately 55.

As the maximum point on this curve is passed, the curve begins to decrease. At a point which is slightly less than halfway between the minimum and maximum points, the curve changes from and increasing to a decreasing slope. This is the point of greatest interest in this paper because it is the point where the crash damage factor corresponding to the slope of the curve begins to decrease or flatten out. This point was chosen for study because it represents a maximum point for the slope of the curve. Thus, it gives a maximum in terms of the calculated crash damage factor. The factor will not get any larger for this particular curve. Therefore it tends to be on the safe side for use as a planning factor. In the case of the UH-1H aircraft, this point occurs where flying hours equal 67.5 (in 100,000 hour increments) and cumulative class B accidents equal 34.6. Proceeding to the other systems, the factors and associated curves for the OH-58 and TH-55 are illustrated in figures 3 and 4.

WALC CONFERENCE PLANNING

The WALC conference uses the Crash Damage (CD) and Peacetime Replacement (PTRF) factors in the following manner:

1. The Number of Aircraft to be lifted to CONUS.
This is developed from the PTRF by multiplying a monthly on-hand assets figure by the PTRF. On-hand assets are expressed in flying hours in a per 100,000 basis. The result is rounded to the nearest whole number.

2. Non-Recoverable losses to Army Inventory.
This is developed from the CD by multiplying a monthly on-hand assets figure by the CD. A per 100,000 flying hour format is used. The result is rounded to the nearest whole number.

Table 4 displays the aircraft studied and their flying hour program in years 1987 and 1988. The PTRF factor is applied to the 1988 flying hour program to yield an estimate of aircraft lifted to CONUS during 1988.

CONCLUSIONS

This paper documents the use of regression analysis which is a commonly used operations research tool. It is applied to aircraft accidents which is a very complex and controversial issue. The tools, techniques and methodologies described in this paper were certainly not intended to be an ultimate answer to the problem of aviation safety. The factors shown in this paper were meant to give an indication of the trends in aircraft accidents. They are better used as indicators over a period of years rather than discrete predictors for a given point in time.

FUTURE ACTIONS

The author is presently undertaking a study which will investigate possible relationships between night flying, the associated use of night vision goggles and increases in major accidents (Class A, B, and C).

TABLE 4

ESTIMATE OF AIRCRAFT LIFTED TO CONUS

AIRCRAFT	FLIGHT HOURS (X100,000)		PTRF	ESTIMATE
	1987 (a)	1988 (b)	(c)	(b-a)*c
AH-1	12.34	13.75	4.0	5.64 or 6
CH-47	6.79	7.41	4.24	2.63 or 3
CH-54	.989	1.07	3.87	.31 or 1
OH-58	3.79	4.09	3.44	1.03 or 2
OH-6	4.05	4.47	2.34	.98 or 1
OV-1	2.63	2.84	7.9	1.66 or 2
UH-1	7.69	8.34	4.16	2.70 or 3
U-8	2.53	2.63	2.74	.27 or 1
UH-1H	8.86	9.50	1.97	1.26 or 2
T-42	2.64	2.72	2.55	.20 or 1
UH-60	4.66	6.29	5.13	8.36 or 9
U-21	6.72	7.28	1.10	.616 or 1

CUBIC FIT UH−1 PRED. CLASS B INCIDENTS

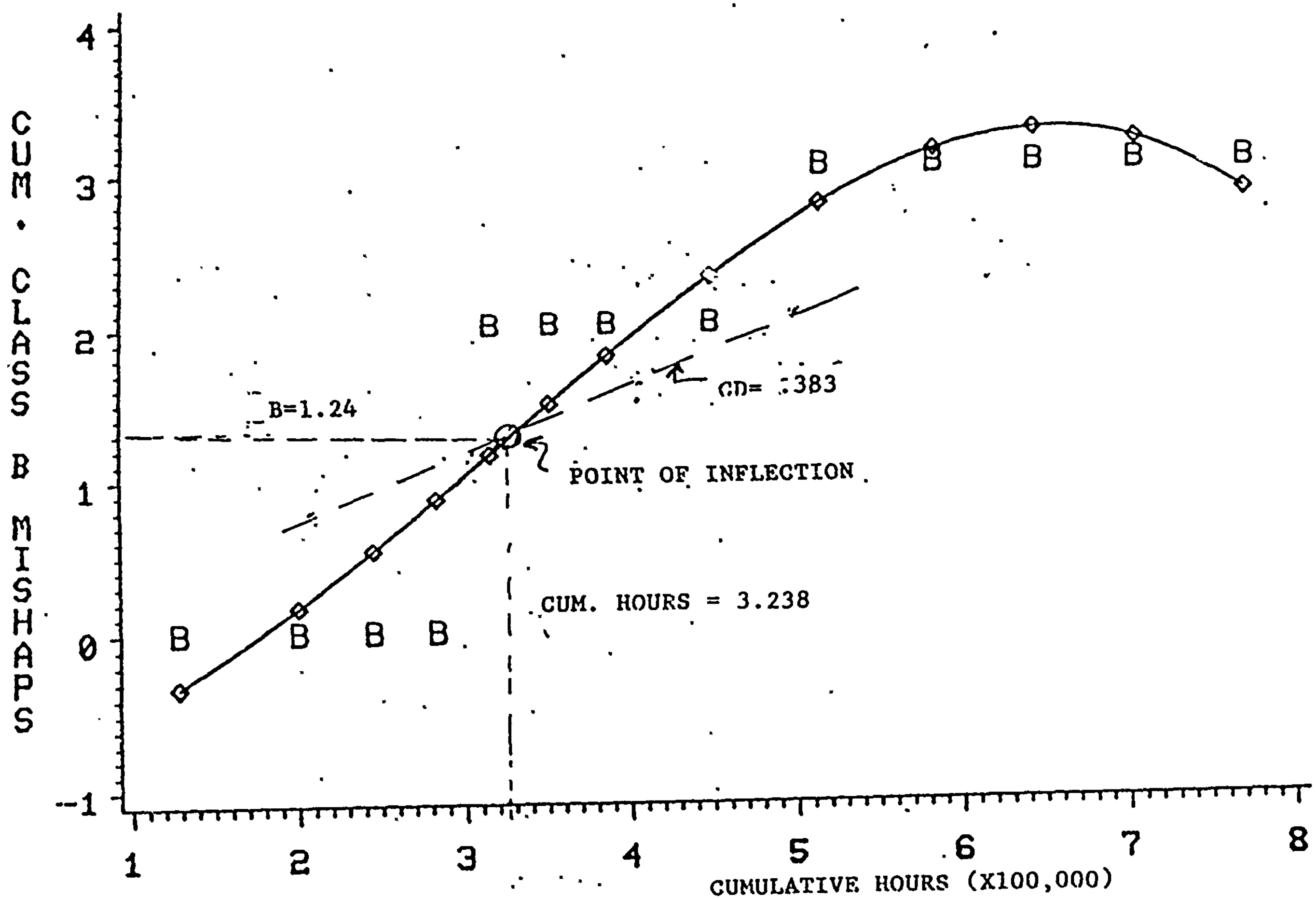


FIGURE 1

CUBIC FIT UH–1H CUM. CLASS B INCIDENTS

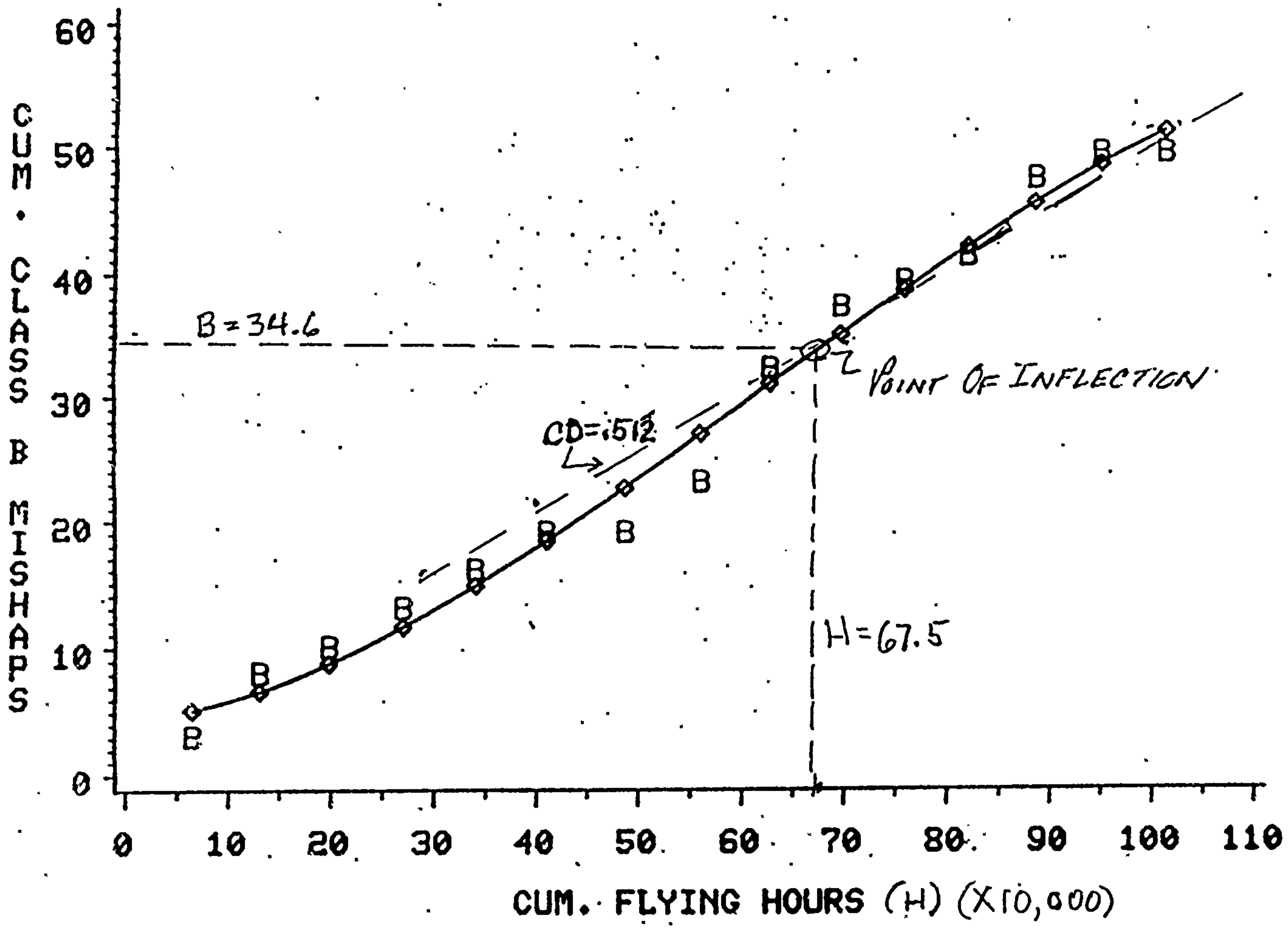
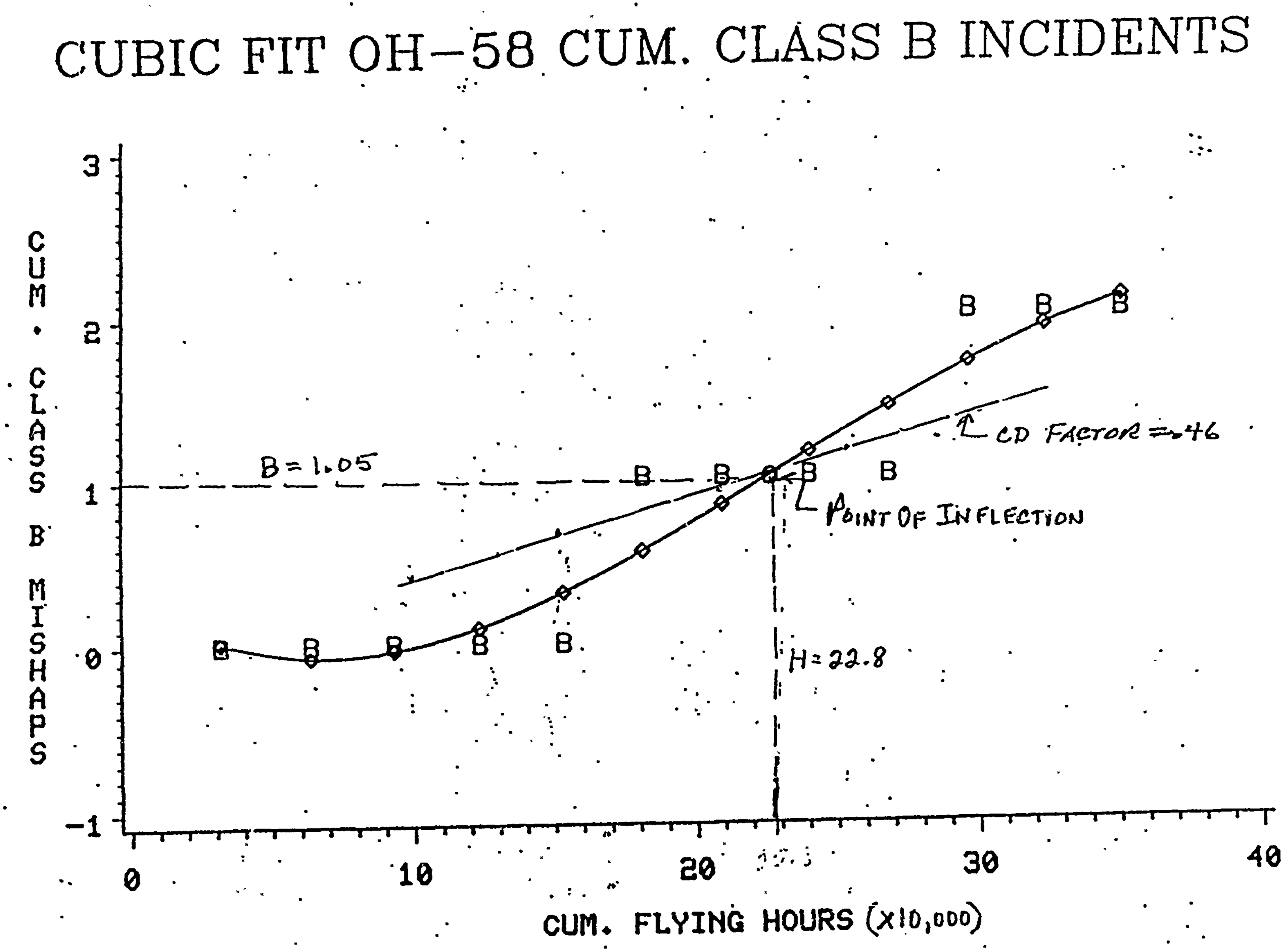


FIGURE 2



CUBIC FIT OH—58 CUM. CLASS B INCIDENTS
CUM. CLASS B MISHAPS
CUM. FLYING HOURS (X10,000)
B=1.05
H=22.8
CD FACTOR=.46
POINT OF INFLECTION

FIGURE 3

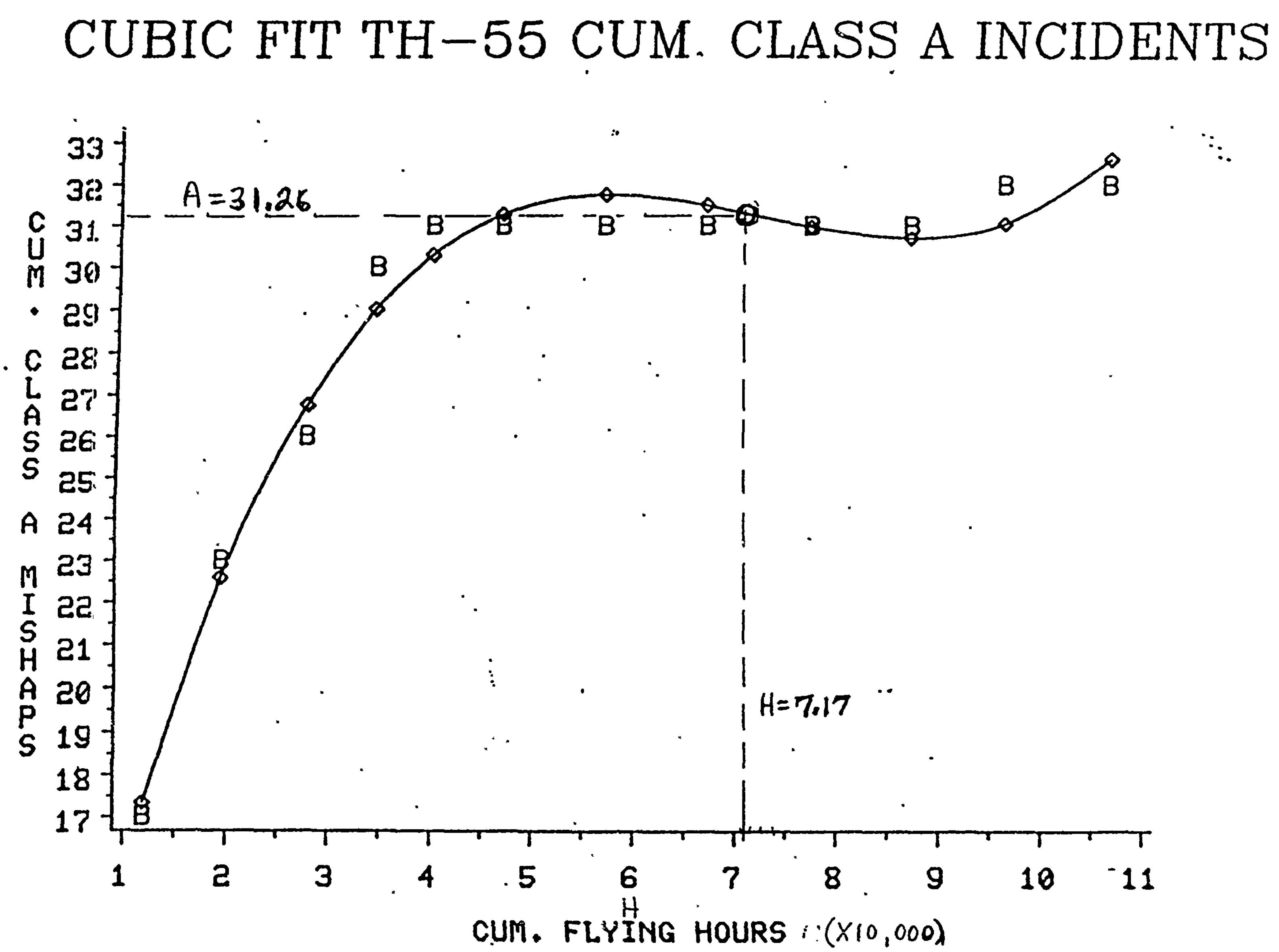

CUBIC FIT TH–55 CUM. CLASS A INCIDENTS
CUM. CLASS A MISHAPS
33
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
A=31.26
H=7.17
1
2
3
4
5
6
7
8
9
10
11
CUM. FLYING HOURS (X10,000)

FIGURE 4

#164

TITLE: HAWK Level of Repair Analysis

AUTHORS: K. McDaniel and W. Hughes

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

As part of AMSAA's evaluation of the Intermediate Family of Test Equipment (IFTE) a level of repair analysis was conducted on the Hawk Air Defense Missile System using the Optimum Supply and Maintenance Model (OSAMM). The HAWK system was chosen because it is the first anticipated user of IFTE.

The study addressed the following:

a. Where should the IFTE be placed?

b. What are the costs/benefits of transitioning to the IFTE from the HFC/GETS 1000 Hawk peculiar Test Measurement Diagnostic Equipment (TMDE)?

Because of the time required to gather the data required to model the entire HAWK system only the high power illuminator (HPI) was modeled. The HPI represents 25 to 35 percent of the total HAWK workload. Since the purpose of the study was to assess IFTE only those line replaceable units (LRUs) that were potentially IFTE testable were modeled (56 LRUs).

OSAMM runs were made for the HAWK using IFTE as the TMDE and time; the present HFC/GETS as TMDE. For the IFTE configuration four scenarios were considered. These scenarios were--

a. Personnel and TMDE common at all echelons.

b. Personnel and TMDE common at depot but peculiar at GS and DS.

c. Personnel and TMDE common at depot and GS but peculiar at DS.

d. Personnel and TMDE common at depot, GS, and DS.

Common means the personnel and equipment support other systems at that level. Peculiar means the personnel and equipment only support the HAWK at that level.

OPERATOR WORKLOAD KNOWLEDGE-BASED EXPERT SYSTEM TOOL (OWLKNEST) DEMONSTRATION

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ABSTRACT

The Operator Workload Knowledge-based Expert System Tool (OWLKNEST) is a microcomputer-based tool that provides guidance in selecting the most appropriate technique to use for assessing Operator Workload (OWL) for developing Army systems. OWLKNEST is based on twenty years of workload research and on knowledge gained in the three-year Army Research Institute OWL Program. The design approach is presented along with a general description of targeted users and the knowledge representation scheme. Sample system applications are presented which illustrate how OWLKNEST can be used for a variety of needs.

INTRODUCTION

Projected manpower declines coupled with increases in personnel costs and battlefield sophistication has prompted an increased reliance on high technology equipment in new Army systems. As technology has changed, the role of the operator has also changed. Task requirements for the operator have shifted from those that primarily require physical exertion to those that demand increasingly larger amounts of perceptual and cognitive exertion.

While technological advancements may increase system capability, it is critical to ensure that the resulting systems do not concurrently cause the demand for mental skills to exceed the operator's capabilities. Task demands greater than an operator's capacity to respond may result in undesirable consequences, such as, mission degradation or failure, compromised system safety, or an insufficient number of skilled personnel.

The concept of work in the physical sciences is readily understood; work is not performed without some expenditure of energy or other resources, and work rate/efficiency may change depending on the demands of the situation. Likewise for the human, both physical and mental work depend not only on the particular task to be accomplished, but also upon the availability of the internal resources required of the operator to perform the task. Thus, operator workload (OWL) is defined in terms of the interaction between the work imposed on an operator by a task and the operator's capacity to perform that work.

A variety of OWL assessment techniques are available and many have been documented in published papers (e.g., Lysaght et al., 1988; O'Donnell and Eggemeier, 1986; Wierwille and Williges, 1980). Workload assessment methods include analytical, or predictive techniques which may be applied early in system design without an operator "in-the-loop" and empirical techniques which require an operator using a simulator, prototype, or representative system. Analytical techniques are used to predict performance and estimate workload through the methods of task analysis, simulation models, mathematical models, and expert opinion. Empirical techniques include methods which measure the operator's performance, obtain ratings of subjective experience, and measure physiological responses.

Operator workload analysts have found it difficult to readily determine which technique is most appropriate for their particular workload study (Hill and Harris, 1989). Aside from a large number of assessment methods from which to choose, the analyst must also consider the objectives of the workload study. For example, workload assessment techniques differ in their sensitivity and diagnosticity. Sensitivity refers to the degree to which the technique can differentiate between levels of workload placed upon or experienced by the operator. Diagnosticity refers to the extent to which a technique reveals not only the overall level of OWL but also information about the component factors that contribute to overall OWL (e.g., perceptual, cognitive, psychomotor factors). The selection of the optimum technique is further complicated by real world constraints (e.g., time, cost, personnel requirements, facilities).

Based on information gathered from Army personnel and documents, it is evident there is a void in specific guidance concerning the implementation of operator workload assessment during the Materiel Acquisition Process (MAP). Developers of Army systems are required to conduct workload analyses during the system development process under the purview of MIL-H-46855B and MANPRINT (see Hill et al., 1987 for a discussion of US Army OWL requirements). In response to this need, the Operator Workload (OWL) Program, that has just been completed, was a three-year exploratory development research effort sponsored by the Army Research Institute (ARI). The OWL program was directed to establish guidance for the assessment of operator workload associated with the operation of Army systems.

APPROACH

Rather than yet another written manual (with its inherent difficulties associated with revisions and usability), the Army community expressed a desire for a computer-based guidance tool (Hill, et al., 1987). As such, one of the products of the OWL Program is the Operator Workload Knowledge-based Expert System Tool (OWLKNEST), an interactive, computerized decision-making aid. As well as providing recommendations for workload assessment techniques, OWLKNEST is also envisioned to serve as a clearinghouse of knowledge for workload assessment methodologies.

OWLKNEST is based upon an expert systems approach. Expert systems technology incorporates knowledge bases to represent human domain expertise and inference engines to mimic human expert reasoning processes. Expert systems have been found to be particularly successful for classification type applications, which recommend an answer selected from a set of alternatives based upon user inputs. Likewise, OWLKNEST provides guidance in selecting the most appropriate OWL assessment techniques based upon user specification of the characteristics of the particular workload assessment goals and resources.

OWLKNEST builds upon the foundation of a prior workload assessment tool, the Workload Consultant for Field Evaluation (WC FIELDE) (Casper et al., 1986). WC FIELDE, developed by NASA, also utilizes an expert systems approach. It includes a number of rules which are used to rank 24 workload measurement techniques, in terms of the appropriateness for the particular circumstances of the proposed study (Casper et al., 1987). OWLKNEST differs from WC FIELDE in two major ways:

(1) Its knowledge base contains both analytical and empirical workload assessment techniques; and

(2) Its emphasis is on those techniques suitable for operational and field testing, especially during the evaluation of Army systems.

Questions with response alternatives are posed to the user regarding issues such as, system and operator characteristics/requirements and workload study resources/capabilities. Based on the user's selection of alternatives, OWLKNEST applies rules and knowledge derived from workload domain experts. The result is a list of appropriate workload techniques whose applicability is rated as High, Average, or Low. Figure 1 illustrates the OWLKNEST flow of information. At any point in the program, the user may ask for help from OWLKNEST to clarify a question, explain a procedure, or show which rules are in operation.

Hardware and Software Environment

OWLKNEST runs on an IBM PC type microcomputer equipped with a minimum of 640 Kb memory and either two floppy diskette drives of at least 360 Kb or a hard disk and floppy diskette drive. It also requires DOS 2.0 or higher. Exsys Professional, a rule-based, backward-chaining system, is the expert system shell used for OWLKNEST.

User Characteristics

The targeted user population for OWLKNEST are the analysts involved in assessing operator workload for a system, for example, an Army MANPRINT analyst or a human factors specialist in a commercial setting. OWLKNEST assumes that users have at least a fundamental knowledge of OWL and human performance concepts, but they can be novice computer/expert system users.

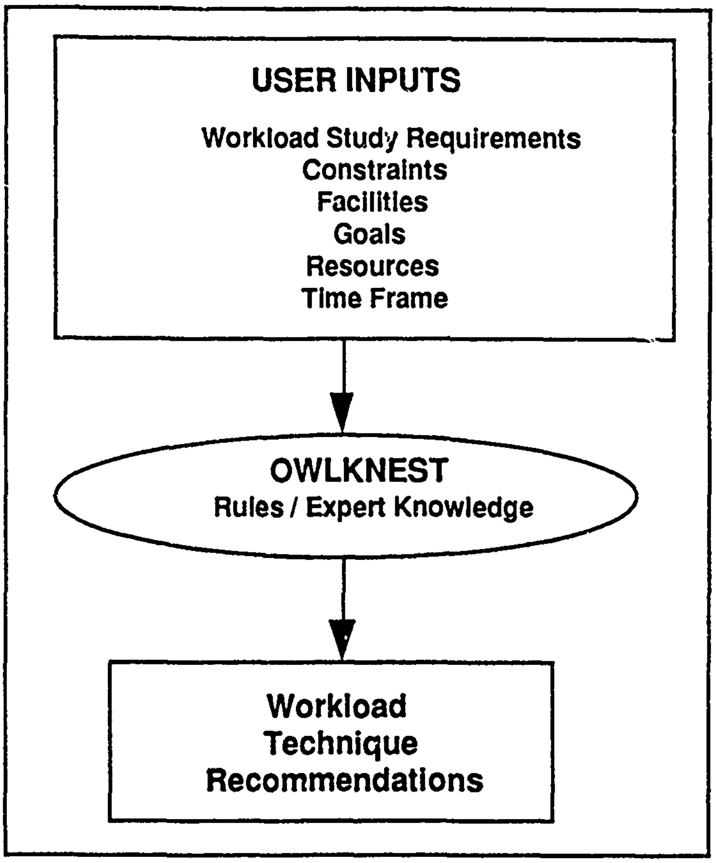

Figure 1. OWLKNEST Information Flow

OWLKNEST Knowledge Base

The OWLKNEST knowledge base is organized according to the taxonomy suggested by Lysaght et al. (1988) which divides OWL techniques into analytical (predictive) and empirical (evaluative) techniques. Within each of these two divisions, other categories of workload techniques were identified. Only those OWL techniques which met the following evaluation criteria were included in the OWLKNEST core set:

1) Demonstrated efficacy in real-world Army applications,
2) Sufficient documentation and validation.

Thirty-eight analytical and empirical techniques met the evaluation criteria and were included in OWLKNEST. These workload techniques were organized into a classification (or decision) tree that resulted in an hierarchical knowledge structure. The upper part of the classification tree is illustrated in Figure 2. Figure 3 shows the full tree for the node that represents the analytical expert opinion techniques. Other nodes shown in Figure 2 can be similarly expanded (e.g., Figure 4 shows the expanded decision tree for the empirical subjective ratings techniques). The terminal nodes of the decision tree structure represent the actual workload techniques. This nested structure provides the capability to readily incorporate new workload techniques into OWLKNEST.

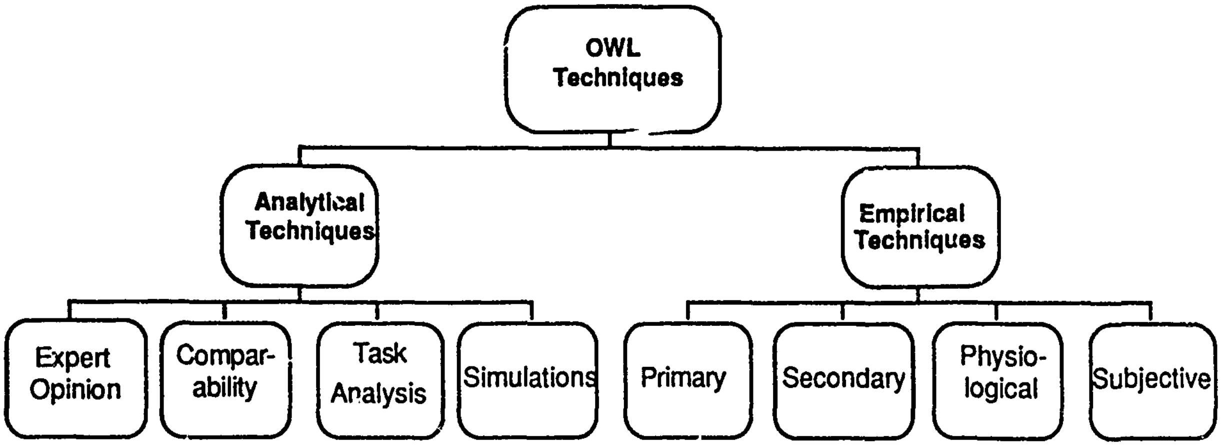

Figure 2. OWL Measurement Techniques Classification Tree

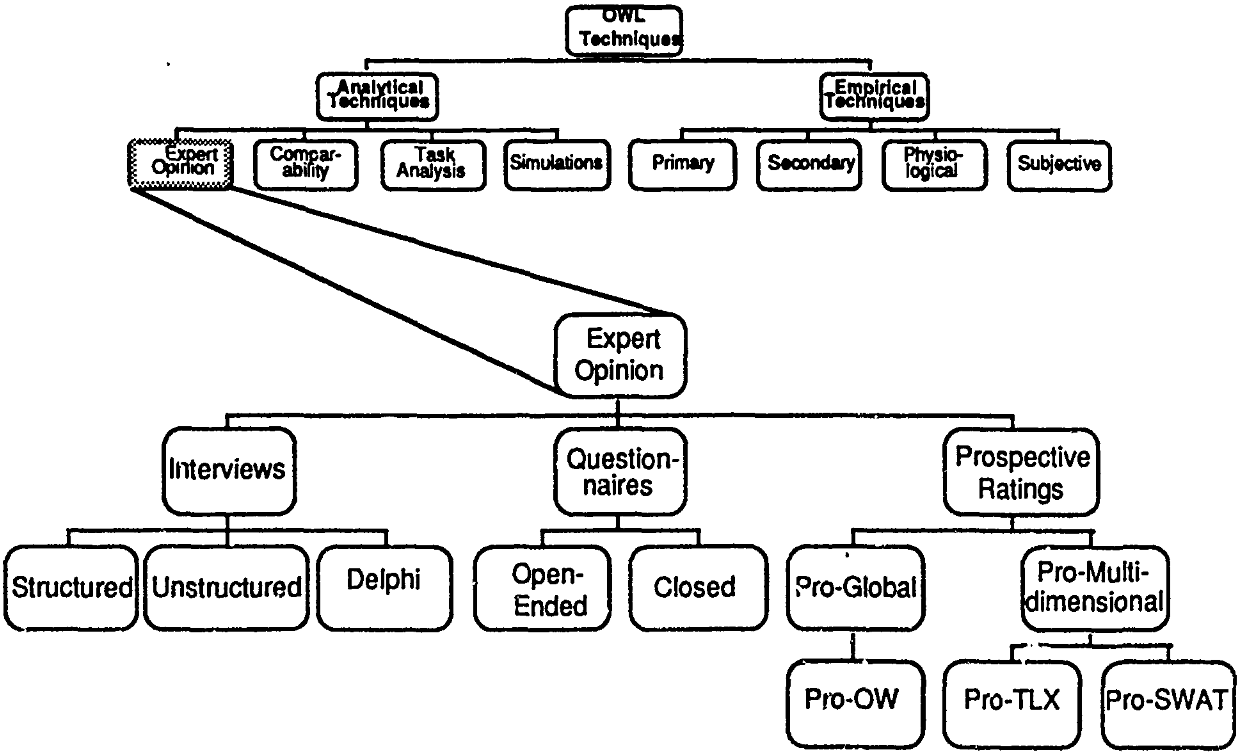

Figure 3. OWL Expert Opinion Techniques Classification Tree

The expert system applies rules to determine the selection and presentation order of questions posed to the user and also to determine the selection and rankings of the recommended techniques. These rules are normally hidden from the user (as are the thought processes of an expert), however, the user may opt to display them. The rules are specified as statements in the form: "If this premise is true, then perform this action or make this conclusion." Each rule is evaluated and when the current condition matches the premise state in the IF rule (i.e., the condition is TRUE), then the indicated action is performed. Both forward and backward chaining procedures are employed as appropriate. Forward chaining matches rules against facts to formulate new facts while backward chaining attempts to prove a new rule by determining what facts are required.

Thirty-seven criteria defining the salient features of workload techniques were utilized in the development of the rules. Some of the criteria are based on facts (e.g., a particular technique requires an IBM PC microcomputer) while others are subjective (e.g., a particular technique is judged "easy-to-use"). The development of the rules was guided by a panel of human factors specialists who totalled over 70 years of experience in assessing workload, as well as by knowledge gained in utilizing OWL techniques in Army settings (Byers et al., 1989; Hill et al., 1989; Iavecchia et al., 1989).

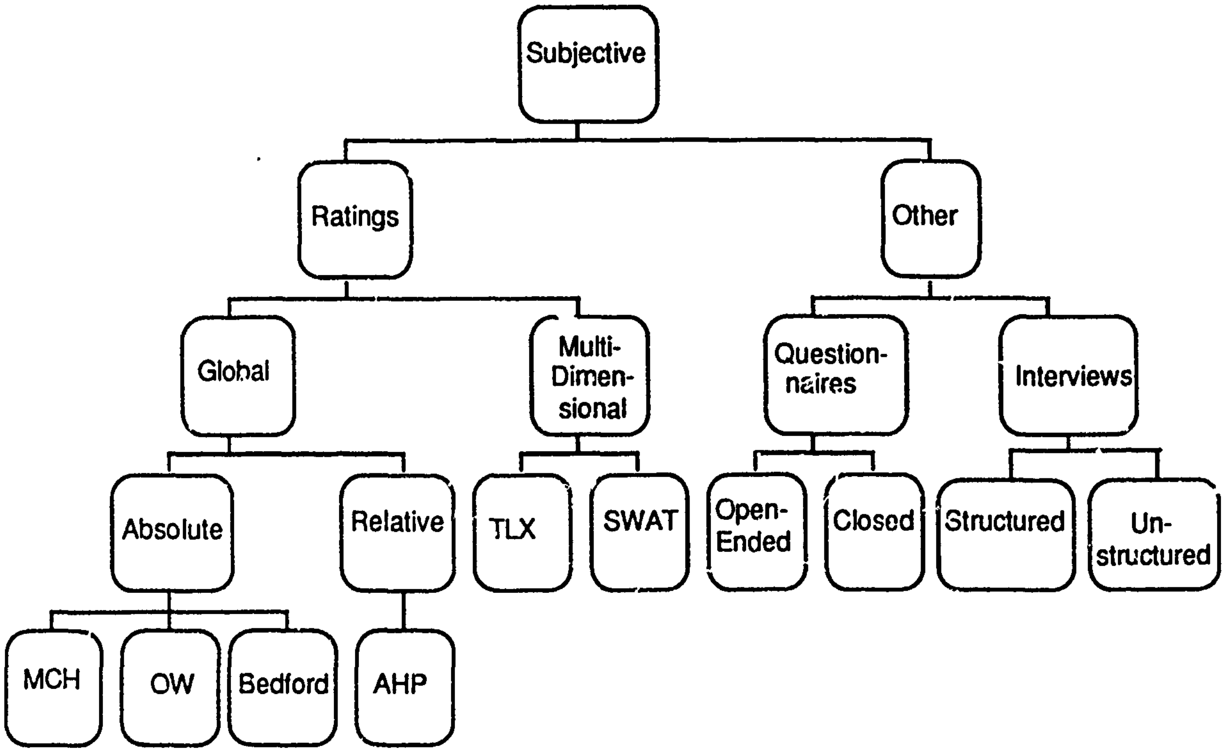

Figure 4. OWL Subjective Measurement Techniques Classification Tree

Rules are sorted into groups. Based upon the user's responses, the initial group prunes the classification tree by determining which branches of the tree, if any, can be eliminated and the second group refines the applicability rankings of the remaining techniques. Questions of resource availability drive the rules which eliminate and the goals of the study drive the rules which refine. Therefore, due to the classification of rules and the logic of the program, the user does not have to answer all 37 questions in order to obtain the list of recommended techniques. For each unique workload study, there will be a unique set of questions posed to the user and a customized list of recommended techniques.

User-Computer Dialogue

OWLKNEST presents a series of questions to the user as illustrated in the following screen:

> The availability of an operator to interact with equipment for the workload study is?
>
> 1 Operator(s) available
>
> 2 No operator(s) available
>
> 3 I don't know
>
> 4 Not applicable

The user enters one or more of the numbered options in response to each question. The last two responses are used when none of the options are applicable to the particular OWL assessment. A response of "I don't know" is used when the user does not possess sufficient information at the present time to answer the question, while a response of "Not applicable" is used to indicate that the question is not pertinent to the problem. These last two responses are used to prevent the expert system from forcing the user to select a clearly inappropriate alternative and subsequently using that response in ranking the OWL techniques. The questions posed to the user are structured to correspond with the knowledge representation scheme depicted in the classification tree. This structure attempts to quickly focus on the most applicable technique(s) by minimizing the number of questions posed by the system.

OWLKNEST Output

OWLKNEST's output is a list of appropriate workload techniques, each with a ranking of High, Average, or Low applicability. The rankings are based on cumulative probabilities generated by the rules underlying each question and responses selected by the user. The origin of the initial probabilities is the consensus of opinion formulated by the panel of workload experts. The rankings prioritize the applicability of the techniques for the particular workload study. The user can optionally access the rules to see what parameters were influential in the determination of the listed results and ranking assignments.

Brief, one-page descriptions of the recommended technique(s) including implementation requirements, usage parameters, resource requirements, references, and points-of-contact (Hill and Harris, 1989) can also be obtained. It is incumbent upon the user to carefully consider which of the workload techniques to implement from the list of OWLKNEST recommendations. OWLKNEST is a guidance-providing tool, not a replacement for the sound judgment of the analyst.

OWLKNEST can be used in several different ways to provide insight on the appropriateness of various OWL techniques. It can be used to address specific circumstances facing the user on the applicability and appropriateness of the OWL techniques at a particular point in time. For example, a workload analysis may be desired early in system design. Then, after the initial development is complete and a prototype is available, OWLKNEST might be used again to suggest workload techniques based on the currently available information and resources. Hence, OWLKNEST can be used throughout the development cycle of the system.

Furthermore, OWLKNEST can be used in a sensitivity analysis mode by changing one or more of the responses given. For example, in the first run, the analyst may choose to respond that no special equipment is available and obtain results based on that answer. In the next run, however, the analyst may want to see what other techniques would be recommended if audio and video recording equipment were available. In this case, the suggested list might include different techniques. For ease of comparability, OWLKNEST can generate a side-by-side display of the previously recommended techniques alongside the current results, each with their respective rankings. In this way, the analyst will be able to make informed decisions as to whether additional resources should be allocated to or required for the workload assessment effort.

APPLICATIONS

To illustrate the use of OWLKNEST, two representative applications are described below.

Case 1: Early System Design

The first case illustrates an early system design study with the following set of conditions:

- Only paper specifications exists and no mockup or prototype is available,
- A general idea of how the tasks should be accomplished has been determined,
- Subject matter experts are available with experience on a similar system,
- No more than a week is available for workload study including preparation and analysis,

- The primary objective is to obtain global workload measures, and

- A well-defined, easy-to-use technique is preferred, particularly in the areas of preparation and analysis.

In this situation, OWLKNEST ruled out empirical techniques since a representative system would not be available for the workload study. The following recommendations would be made for analytical techniques:

Closed Questionnaires	High
Open-ended Questionnaires	Medium
Prospective-OW	Medium

Prospective-OW and open-ended questionnaires would probably require more analysis time than the user has available and therefore are assigned a lower ranking. The ranking for Prospective-OW is further lowered because the technique is not particularly well-defined. (Refer to Lysaght et al., 1988, for discussion of the various techniques mentioned in this paper.)

Case 2: Test and Evaluation

The second case represents a study of a more mature system for which there is to be some form of operational test of the system. The study has the following set of conditions:

- Both representative operators and a system prototype are available,

- Detailed descriptions of the operator tasks are available,

- A well-defined methodology is preferred,

- About a month is available for workload study with a week each for preparation and analysis, and

- The primary goal is to discriminate sources of workload.

For this case, OWLKNEST recommendations would include the following:

Closed Questionnaires	High
Open-ended Questionnaires	High
Embedded Secondary Task	Medium
SWAT	Medium
TLX	High

The ranking for embedded secondary task was lowered because it typically requires more than a week for data preparation and analysis and is often difficult to implement in an operational setting. The ranking for SWAT was lowered because operator acceptance of SWAT has been found to be low (Hill et al., 1989; Iavecchia et al., 1989). Questionnaires and TLX met all of the user's criteria and were therefore given a high ranking.

CONCLUSIONS

One of the goals of operator workload assessment is to contribute to the processes that ensure acceptable system and human performance. These processes may include:

1) Prediction of the impact of operator workload on the design and performance of proposed Army systems;

2) Effective allocation of workload-imposing tasks among soldier, hardware, and software components of systems and assessment of the influence of workload factors on the organizational design of Army units; and

3) Establishment of procedures for the selection, classification, and training of soldiers to effectively cope with operator workload in operational situations.

Those who wish to predict or evaluate operator workload will find expert advice at their fingertips when they use OWLKNEST. OWLKNEST will recommend and supply information on appropriate OWL techniques based on user inputs regarding the goals and resources of the particular workload study. OWLKNEST is applicable across all phases of the materiel acquisition process, from early concept exploration through full scale production and deployment. It is a comprehensive, easy-to-use tool which emphasizes techniques suitable for operational and field testing.

Refinement of the OWLKNEST knowledge base will continue as more information and experience with the suggested techniques is obtained and as other workload techniques are identified for inclusion. The guidance provided by OWLKNEST will be further validated in future studies. More complete information about utilizing OWLKNEST can be obtained in the user's guide - Handbook for Operation of the OWLKNEST Tool (HOOT) (Harris et al., 1989).

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Nuclear/Conventional Interactions in Battlefield Operations

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Introduction

Combat is a complicated enterprise. Simulating combat on a computer is no less complicated; it may even be harder (even if less lethal). Despite this, the role played by computer-based combat simulations to help answer vexing force structure and doctrinal issues is increasing steadily. So too is the complexity of these models. These two facts challenge the military analyst's capability to identify cause and effect relationships, which often are obscured by the shear mass of data generated by simulations.

The research discussed in this paper illustrates these assertions. The purpose was to identify (and quantify if possible) how nuclear weapons influence corps operations and plans. If nothing else was learned, this study demonstrated that some commonly used measures of effectiveness (MOE) do not adequately capture the essence of the simulated combat. In many respects, the work served as a case study showing the importance of the capability to examine simulation results with a graphics-based postprocessor as a way to interpret what happened and why.

Study approach

Janus[1] was used to examine the utility of small-yield (five kilotons or less) nuclear weapon support of a counterattack in a European setting by a corps reserve force (blue) against a larger aggressor force (red) that was not similarly constrained. The study described here represents one portion of a much larger conflict that was studied using other simulations. Table 1 describes the forces possessed by both sides. Blue forces represent an armored division supported with two aviation battalions and a portion of the corps artillery. Red forces represent two second echelon divisions (one tank and one motorized rifle) of a first echelon combined arms army. Additional supporting army and *Front* forces are included as appropriate.

Two plausible scenarios for the counterattack were developed. One in which nuclear weapons are not used, to establish a baseline and test concerns surrounding the reproducibility of results from interactive battle simulations. The other scenario is identical to the former except that nuclear strikes representative of a typical selective employment plan (SEP) are executed during the counterattack to rescue a deteriorating tactical situation.[2] Figure 1 graphically portrays the counterattack plan. The mission was to force deployment of the two second echelon divisions inside the corps main battle area and subsequently adopt blocking positions from which to defend against the second echelon army.

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Table 1 Number of weapon systems at start of simulations.

Type	Blue	Red
Tank	348	430
Infantry fighting vehicles	424	714
Artillery		
Gun and howitzer	128	1272
Multiple rocket launcher	36	174
Surface-to-surface missile	6	20
Total	170	1466
Helicopter	198	140
All other	224	238
Totals	1364	2988

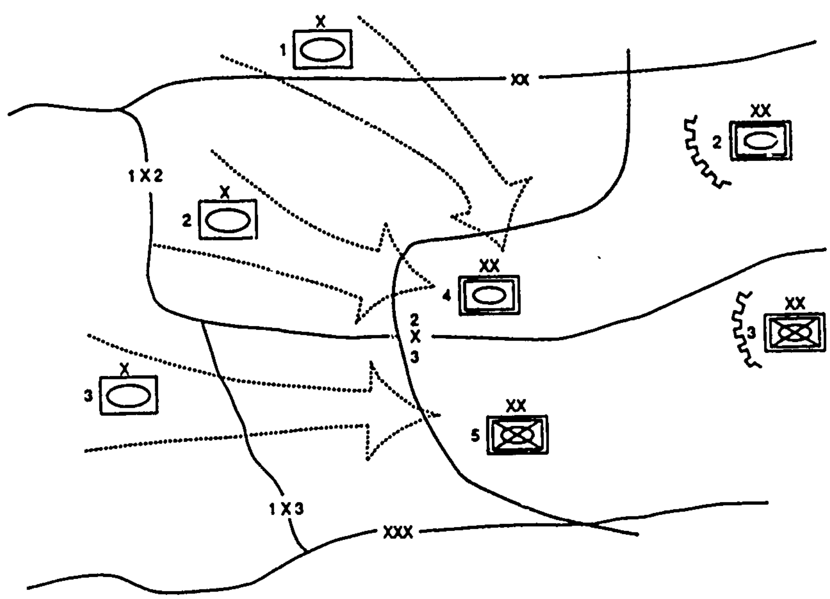


Figure 1 Schematic of corps counterattack plan. Blue forces execute a phased withdrawal to draw the westward moving red forces into a salient. Brigade boundaries of the blue forces prior to the withdrawal are shown. Once formed, the salient is attacked by the armored division deploying two brigades to the north and one to the south along the indicated axes. Remnants of two red force first echelon divisions (defeated earlier) have adopted hasty defensive positions as shown; another is off the sketch to the north.

All games share the same first 100 minutes of simulated combat. Six combat simulations were completed; three conventional and three nuclear. Red retaliatory nuclear strikes were delivered in the first two nuclear games, none in the third.[3] The reason for prohibiting a red retaliatory strike during the last game was to examine how much advantage accompanied a one-sided strike.

Often analysts treat various ratios (for example, force ratios and loss exchange ratios) as important MOE without reference to the absolute quantities involved. This can lead to absurd situations where the ratios look fine but the final numbers themselves tell a different story. For example, suppose one side must retain sufficient combat power to be able to battle follow-on forces before reinforcements can arrive. In this case, simply having a favorable force ratio at the end of the first battles may not be sufficient if only a small fraction of the original force remains to deal with the next echelon. The approach adopted in this study is to supplement such MOE with time-dependent force levels so that the reader can more easily judge battle success.

There is a tendency to correlate the effectiveness of theater nuclear weapons with the number of personnel (or crews) exposed to lethal levels of radiation or weapon systems damaged or destroyed. But such an approach is shortsighted. It tends to ignore tactical advantages that can accrue from the use of such weapons. For example, nuclear weapons can be used, in principle, to canalize enemy forces into kill zones on the battlefield where other weapon systems can exact their toll (and take credit for the kills). Unfortunately, the more common MOE, such as force ratios and loss rates, do not help quantify such a potential tactical advantage of nuclear weapons. Because the flow of a battle simulation can be captured for subsequent review, Janus provides a mechanism for forming admittedly subjective judgements about the utility of nuclear weapons.[4] Once postulated, such insights or trends can be examined in more detail.

Another important consideration is how one decides that a particular game is over. In this study, game completion was determined subjectively; the game was brought to a close when it seemed that nothing more of interest was likely to happen. This introduces a degree of imprecision when comparing endpoint results among games ending at different times, but the error is judged to be small. Besides, it is not clear that simply letting games proceed to some arbitrary stop time would provide better results.

Results and discussion

Before describing game results in detail it is worthwhile to note some general observations about artillery play in these simulations. Direct support missions are planned and executed automatically in Janus, general support missions are planned and executed by a player. Artillery fires do several things on the Janus battlefield. They obscure maneuvers with smoke, create obstacles by delivering mines, and suppress or destroy other forces with HE, DPICM, Copperhead, and nuclear weapons. A problem associated with assessing the effectiveness of artillery is that while it is easy to count forces destroyed by artillery fires, it is very difficult to account for less destructive but no less important effects, for instance, communication disruption attendent with destroying vehicle antennas. A different problem is knowing how to model these kinds of indirect effects. Such indirect effects are not modeled in Janus. Another potential problem is ensuring that the players use their artillery correctly. In this study, the red force lost about half of its starting complement of artillery systems. But it is not clear how well this result reflects reality because, in fact, neither side was effective in conducting counterbattery fires and periodically displacing firing units to new locations as stipulated in their respective doctrines.

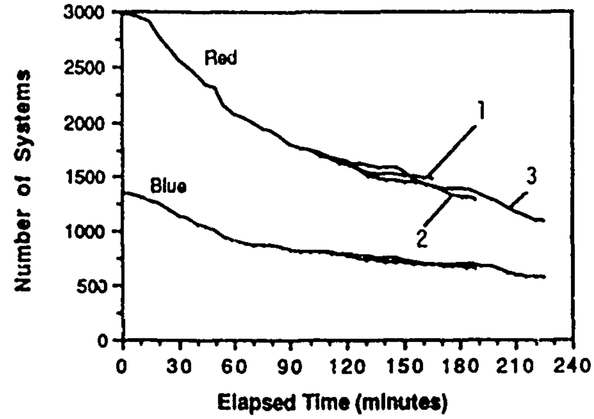
Conventional baseline

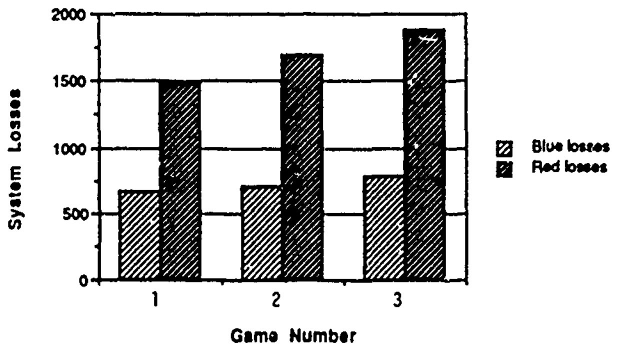
Figure 2 shows time-dependent force drawdowns and game endpoint total losses and loss exchange ratios (broken out by losses due to direct fire systems, indirect fires, and both) for the three conventional games. Note the consistency among the results in all of the measures. This suggests that player learning, always a consideration in interactive simulations, was balanced between the two sides and not a dominant factor. Comparing total system losses at game endpoints for the three games indicates a gradual increase for both sides, which is attributed primarily to progressively longer games and, to a lesser degree, to increasing player proficiency (more so in tactics than in model mechanics). But the marked uniformity in loss exchange ratios argue that player learning was comparable on both sides. At least, one cannot argue that there is an obvious imbalance in player learning rates.

Game No. 3 was designated as the conventional baseline for this study because it was at the peak of player learning. Figure 3 shows time-dependent results from this game in more detail. Force levels and losses for each side and the respective ratios (for all systems and maneuver systems; *i.e.*, tanks, infantry fighting vehicles (IFV), and artillery systems) are shown. One can see that the surviving force ratios remain fairly constant throughout the simulation. Blue forces must destroy more than twice as many red forces as they lose simply to maintain the unfavorable initial force imbalance. Although blue forces managed to destroy around two and a half red systems for each blue system lost, quite respectable for a counterattack, they were unable to turn the force imbalance around to their favor.

Examination of these results provokes an interesting question. Why did the blue forces do as well as they did? Defending forces are generally expected to exact a high toll on attacking forces, but the battles here are really meeting engagements where both sides are attacking. One can speculate about the reason for the result obtained in this work. Maybe it is because blue forces seized the tactical initiative, or maybe it is because blue helicopter forces were utilized more skillfully than were their red counterparts (a subjective observation by the blue aviation player), or maybe it is simply due to differences in the quality of the weapon systems.

Examining force ratios as a function of time provides a better feel for how battles develop and progress than by simply looking at endpoint conditions. With the additional benefit of having reviewed all of the battle simulations reported in this study (using AWS), the results shown in Figures 2 and 3 can be explained. Blue forces initially lose tanks faster than red forces do for the first 15 minutes or so of battle. During this period blue forces are establishing contact and attacking the first echelon regiments. This is followed by a period of sustained battle during which loss exchange ratios rise, ultimately reaching about 5:2. Two reasons seem to be responsible. Despite commitment of second echelon regiments during this period, blue forces are able to develop mass and press home their attack. Simultaneously, red forces–especially first echelon regiments–attempt to disengage and continue their westward movement towards their immediate objective.





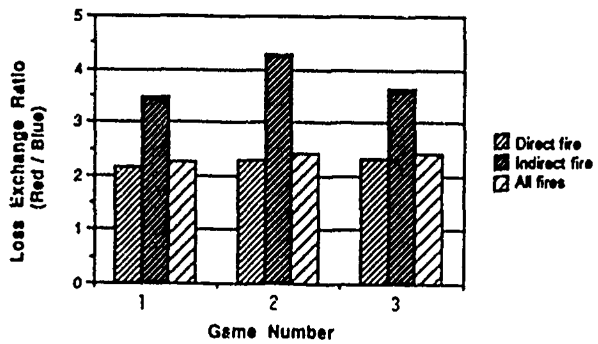


Figure 2 Total force drawdown for both sides is shown as a function of simulation time for the three conventional combat simulations; all games share the same first 100 minutes of battle. Overall system losses for both sides and the loss exchange ratios (red losses divided by blue losses) reflect game endpoint conditions. Loss exchange ratios are segregated by cause of loss; that is, the ratio of losses due to direct fire systems, *etc.* The results show remarkable consistency, differing mostly in a gradual rise in the total number of systems destroyed by both sides, which might simply reflect the gradual increase in game time for the three simulations. The consistency suggests that improvements in player proficiency was balanced on both sides and not a dominant factor in the battle outcomes.

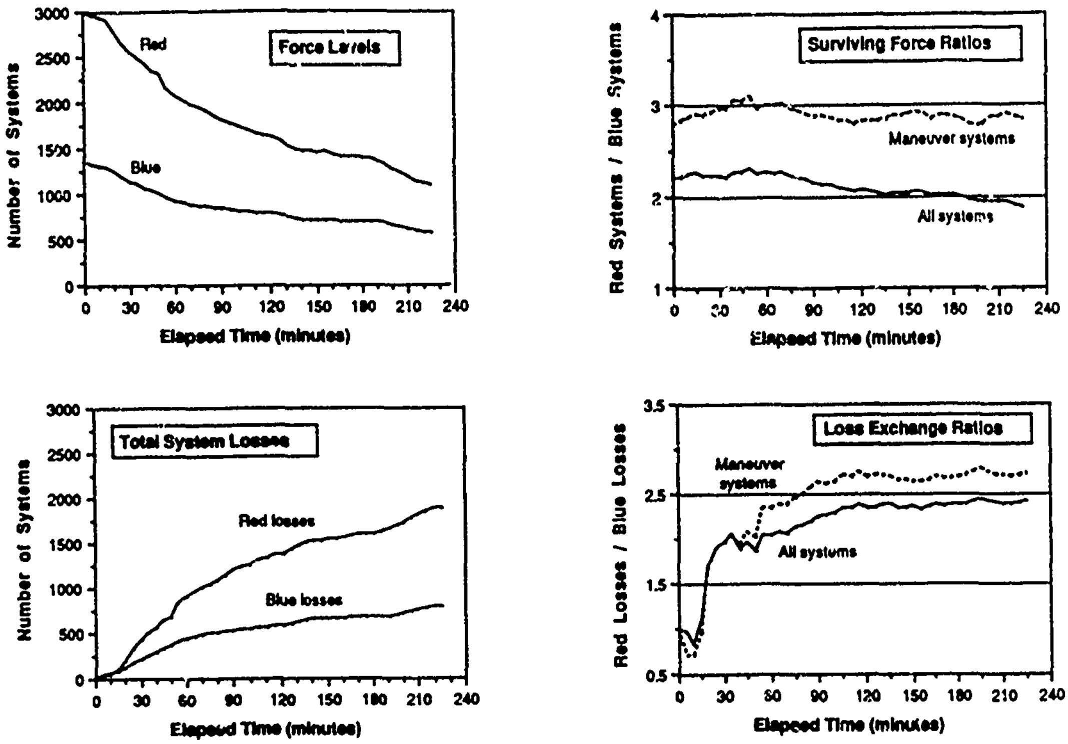


Figure 3 Time-dependent displays provide more information about how battle progressed than by simply examining game endpoint conditions. Total force drawdown and overall system losses for both sides are shown as a function of simulation time for the baseline combat simulation. Time-dependent ratios of surviving forces and losses are shown both for all systems and for maneuver systems; the latter are composed of tanks, IFV, and artillery systems. Maneuver system loss exchange ratios are high and in blue's favor, but not high enough to offset the initial maneuver force ratio of about 2.8 to 1 in red's favor.

In a narrow sense, it is correct to say that the counterattack accomplished its mission during these simulations because the second echelon divisions were forced to deploy into battle formations within the corps main battle area. Red forces were denied the ability to transit the main battle area unscathed; they were forced into combat by the counterattacking armored division. Although blue forces were able to establish defensive positions, they do not have very much combat power left to maintain a viable defense–blue forces are down to 40% of their initial strength. As for the red forces, the TD was essentially defeated in place and about a regiment's worth of the MRD forces managed to pass through the main battle area and continue towards its objective.

Nuclear SEP Execution

Table 2 describes the nuclear strikes employed by each side in terms of number of weapons detonated (both sides experienced duds, consistent with the appropriate reliability factor). One way to characterize the efficiency of these strikes is to account for the casualties directly attributable to them. For example, in Game No. 4, blue forces exploded 21 nuclear weapons that collectively destroyed 91 red weapon systems. Two points may be made: The relative efficiency of each side's nuclear strikes remained roughly constant over the games, and blue used its fewer weapons much more efficiently than did the red side.

Table 2 Description of nuclear strikes for the nuclear simulations.

Game	Weapons detonated Blue	Weapons detonated Red	Systems Killed Blue	Systems Killed Red
4	21	111	110	91
5	42	133	125	136
6	29	-	-	93

A continued frustration to blue force strike planning was how rapidly red maneuver forces moved coupled with the relatively small lethal radius of the blue force's nuclear weapons. Although somewhat larger yield weapons were available for Lance, the 20-minute delay between fire mission receipt and missile launch severely restricted the utility of Lance against fluid close-battle maneuver targets.

Given the paucity of tactical intelligence available to the players, it was of interest to determine how each side targeted its nuclear weapons. In large measure, this can be deduced by examining what was destroyed by the nuclear strikes. Figure 4 shows how nuclear losses during each game were apportioned among the target types. One can see that artillery makes up more than half of the targets killed on both sides. Blue strikes show an interesting trend. In each subsequent game, blue nuclear targeting was increasingly devoted to counterbattery fires at the expense of targeting key maneuver elements.

Explaining why the nuclear strikes were allocated the way they were is not so easy. The red fire plan focused on targeting everywhere except on their planned axes of advance. Since blue maneuver units rapidly closed with red forces, few were subjected to nuclear attack, leaving artillery and other units to bear the brunt of the red strikes. The explanation for the blue strikes is less clear. During the first nuclear game, blue nuclear strikes were split between identified maneuver units and critical terrain. The latter tended to be where artillery units were located. During the second one, blue maneuver was generally more aggressive, quickly closing with the red maneuver forces, which tended to inhibit nuclear use (by both sides) against maneuver units for troop safety considerations. During the last nuclear game, blue maneuver remained aggressive and the blue fire support player consciously focused on counterbattery fires with nuclear weapons.

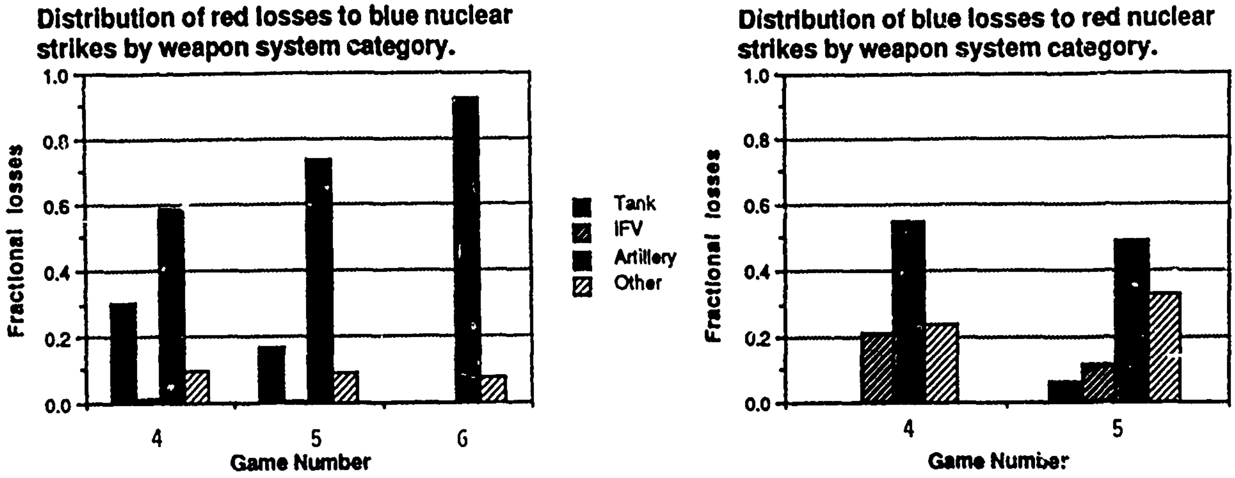


Figure 4 The distribution of losses to the nuclear strikes is shown for each side. For each game and each side the fraction of all direct losses attributed to nuclear strikes during the game is shown broken out by tanks, IFV, artillery systems, and all other systems. In general, both sides concentrated nuclear attacks against nuclear-capable artillery. Attacks on maneuver elements were inhibited by their proximity to one's own troops.

Another way to characterize the direct effect of the nuclear strikes is to assess the fraction of the opposing force destroyed. Table 3 shows percentage losses of all systems and for two subsets of systems: armored forces, consisting of tanks and IFV, and artillery systems. To approximate the fraction of forces destroyed by the nuclear strikes, these percentages are based on the force levels reflected in the data dump immediately preceding the first nuclear strike against a side. Strikes occurred at different times during the various games. A more accurate representation is not obtainable from the data. Basing the percentage losses on initial force levels, though easy to calculate, understates the effectiveness of the nuclear strikes.

Table 3 Percentage losses to various force components from nuclear strikes for the nuclear simulations.

	All Systems		Armored Systems		Artillery Systems	
Game	Blue	Red	Blue	Red	Blue	Red
4	15	6	7	6	37	6
5	27	8	7	4	39	10
6	-	7	-	0	-	9

Blue attacks generally destroyed about six to eight percent of red forces reasonably distributed over the categories shown (though one should remember that six percent of red artillery forces is about 90 systems. Red attacks, which landed mostly on artillery forces, destroyed more than a third of blue's artillery.

Turning now to the value of nuclear weapons, it is important to keep in mind that the results discussed in this report reflect a specific scenario. It would be a mistake to assume that the results necessarily have widespread applicability, though they may. Figure 5 shows selected results for the three nuclear games and the baseline conventional case. The origin of the time scale for the force drawdown curves has been suppressed to amplify differences among the games; all began from the same 100-minute dump. Note that in terms of system losses and loss exchange ratios at game end there is nothing to distinguish the nuclear games from each other or from the conventional baseline. However, the games are in fact different from one another, as the force drawdown curves show.

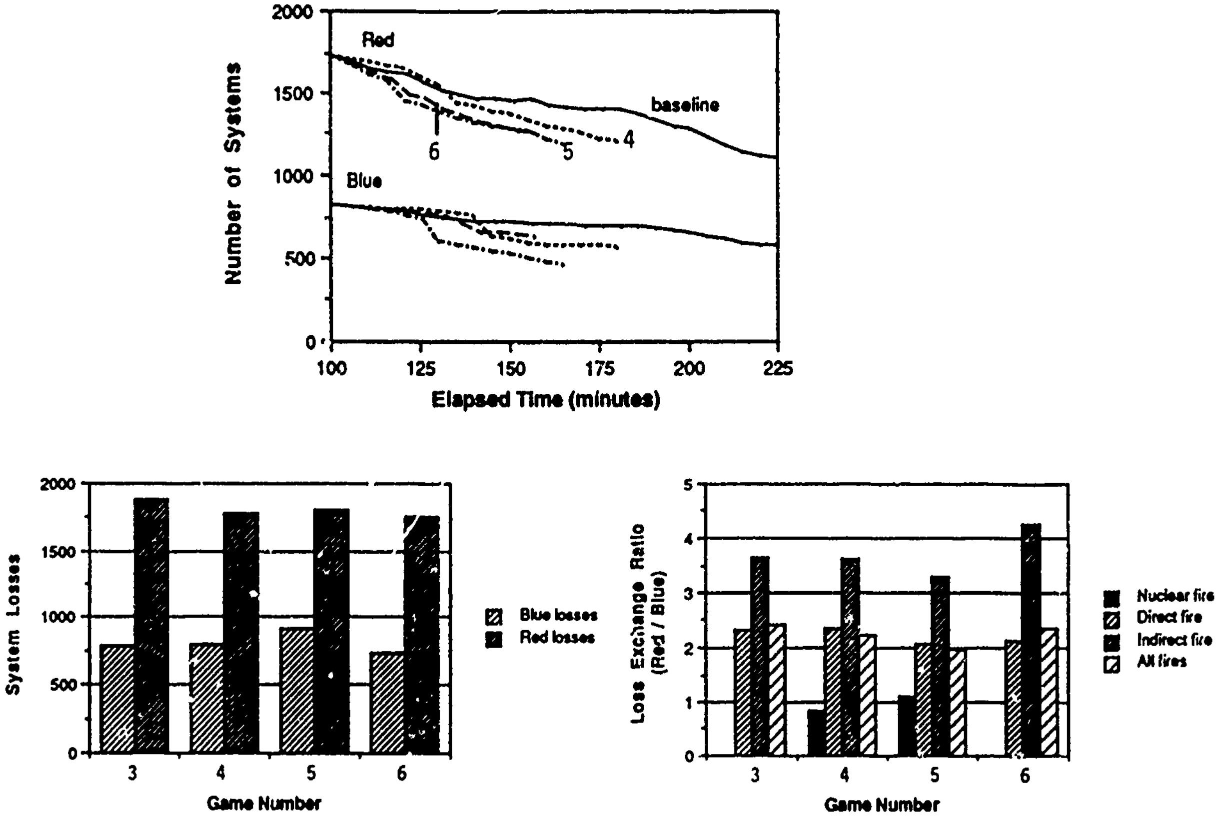


Figure 5 Total force drawdown for both sides is shown as a function of simulation time for the baseline case and the nuclear combat simulations; all games share the same first 100 minutes of battle. Overall system losses for both sides and the loss exchange ratios (red losses divided by blue losses) reflect game endpoint conditions. Loss exchange ratios are segregated by cause of loss. Another category has been added to show losses that are directly attributed to nuclear strikes. Only the force drawdown curves show mentionable differences among the game results displayed.

Because the large amount of artillery available to the red force (initially 1466 systems to the blue force's 170 systems) dominates overall force ratios and obscures fluctuations in fighting vehicle force ratios it is helpful to examine the tank and IFV force ratios separately; these are shown in Figure 6. The battle reflected in the baseline case has already been explained. The nuclear games are explained below.

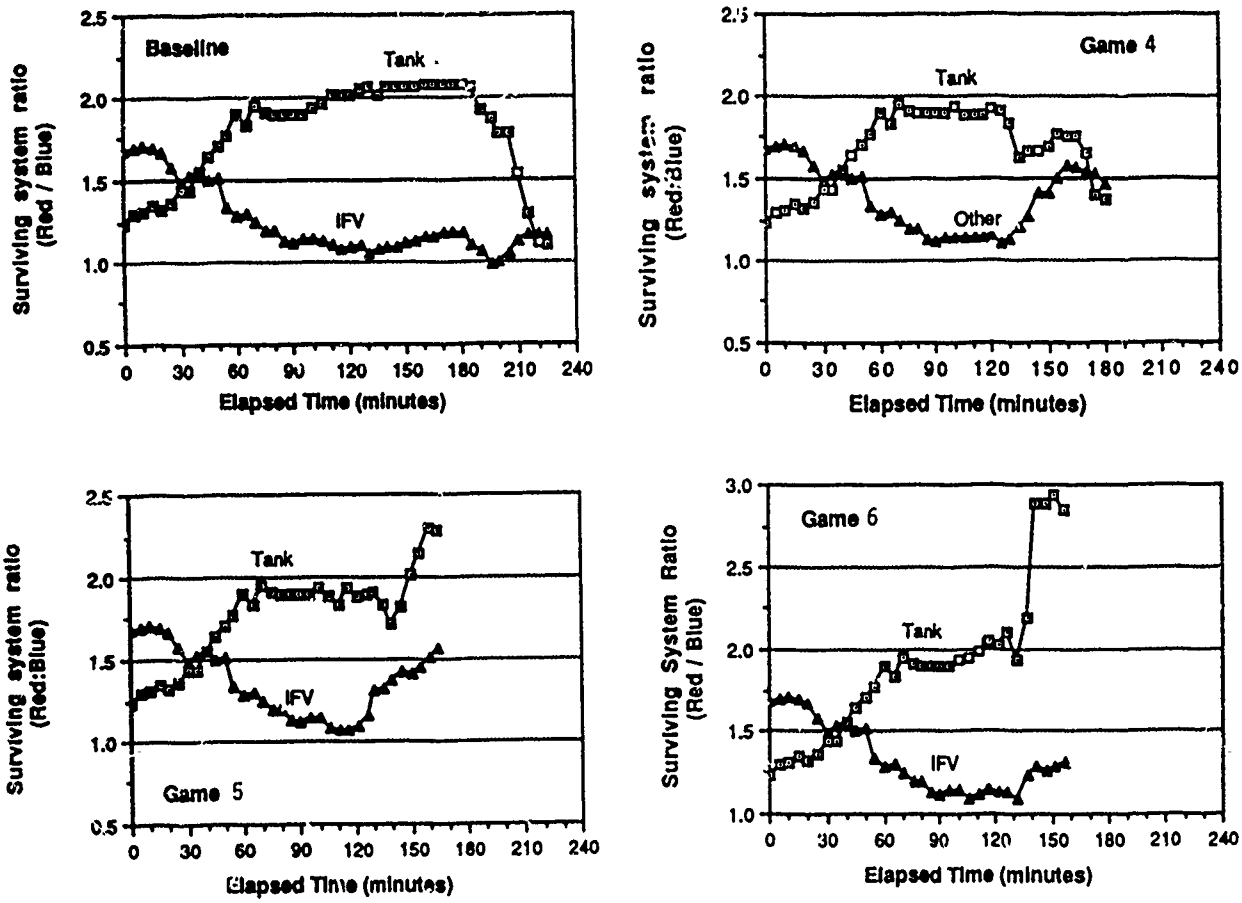


Figure 6 Instead of maneuver force ratios, time-dependent tank and IFV force ratios are shown separately for the baseline and the nuclear games. Artillery forces were excluded because the vast imbalance in artillery force levels, which is initially more than 8:1 in red's favor, dominates maneuver force ratios and obscures what is happening to the ground combat forces. The results shown indicate marked differences among the various games. The explanation for the differences is connected to how the maneuver battle progressed during each game. See the main text for details.

The nuclear strikes in Game No. 4 (the first nuclear game) had minimal effect on the close battle. One reason for this is that neither side displaced artillery forward to keep up with their advancing maneuver forces. When time came to deliver nuclear strikes many identified targets were out of cannon artillery range–

especially for the blue force–and too fleeting for nuclear missile attack. One can see the loss of red tanks by the blue nuclear strike (at approximately 120 minutes into the battle) and (barely) the loss of blue IFVs due to the red strike. The only other differences from the baseline case is that the battle drew to a close a little quicker and the final surviving maneuver system ratios are higher (although the ratios are lower at corresponding times into the battle). Neither side appears to have successfully exploited their nuclear strikes.

In Game No. 5 the *blue* nuclear strike is the indirect cause of significant *blue* losses, seen in Figure 6 as the second upward ramp in the tank force ratio. The explanation, and an important implication drawn from it, is embedded in the tactical maneuver during this game. The MRD axis of advance went west through the southern portion of the battle area (3 Bde area of responsibility). A portion of the blue nuclear strike was planned to attack elements of the MRD along its axis. When the strike was delivered, the red force commander was forced to redirect his movement either to the south, which he did during Game No. 4, or to the north, which he did in Game No. 5. By moving north he left the 3 Bde area and crossed into 2 Bde area. The 2 Bde player had never dealt with those forces before, a problem due to preconditioning from all previous games, and was caught quite by surprise–his forces were aligned to attack the southern regiments of the TD. Consequently, when this true meeting engagement occurred, blue forces were soundly thrashed. The important implication is that blue nuclear strikes could have forced the MRD to divert north, by using additional nuclear weapons along the southern flank of the axis of advance. With that plan in mind, blue forces could have been waiting in ambush instead of being caught unawares. Results would likely have been far different with 2 Bde blue forces being the victor instead of the loser. Previous thought about use of nuclear weapons in support of battle have focused on using conventional forces to canalize the enemy into a lucrative nuclear ambush. This idea would change it around so that nuclear forces would be used to canalize the enemy into a conventional ambush. Further study of this tactic is warranted.

Results for Game No. 6 are suspect. The large spike in the tank force ratio is due to heavy direct fire losses that happened when 3 Bde was flanked by the MRD. But the flanking maneuver was accomplished by a complicated (and unrealistic) retrograde maneuver that was a product of player 'gaming' not likely to occur if the red force commander was responding to both his mission and the way the battle was developing. This circumstance was unfortunate because this game was distinguished by several other interesting differences: There was no red retaliatory strike, there was virtually no red conventional counterbattery fires, and blue nuclear strikes were almost exclusively directed against red artillery. On the other hand, they serve to illustrate the importance of being able to examine battle simulations in detail after the gaming is finished. The unrealistic maneuver is clear on the AWS replays, but not easily discerned from an examination of the usual MOE.

Results from these three games support a very important observation. At least for the scenario examined here, the often stated claim that NATO forces would be worse off after a comparable nuclear exchange with Warsaw Pact forces than they would have been if nuclear weapons had not been used is not correct. The results show that compared to no nuclear use, blue forces did not fare worse than when nuclear weapons were used, even when the exchange was not comparable (a massive red strike compared to the blue strike).

Insights and findings

Collectively, these simulations have provided insight into the utility of specific low-yield nuclear weapons in support of a corps-level counterattack. Some of the findings derive from quantitative results, others derive from qualitative impressions developed by watching the simulations unfold and by re-examining certain aspects in detail using AWS after the games had all been completed. Undoubtedly, some of these findings have applicability to other scenarios, but extrapolations to other scenarios must be done with care. For example, nuclear weapons with different characteristics (yield, accuracy, responsiveness) or different employment areas (tens of kilometers behind the FLOT) could show different results. Some of the following observations may seem either obvious or at least old in the sense that they point out things demonstrated many times before in other studies. But that is not unimportant, because they have been drawn from an interactive, two-sided simulation of a battle scope never attempted before:

- MOE commonly used in studies of the effectiveness of nuclear weapons may not adequately capture the weapons' utility. Force levels and ratios at the end of a simulation do not necessarily represent how nuclear weapon use contributes to overall battle success or failure. At a minimum, how those measures change as a function of time should be examined. Furthermore, the degree that nuclear weapons support mission accomplishment is not necessarily related directly to the number of "nuclear kills." Use of nuclear weapons influences subsequent maneuver and other aspects of nuclear warfare not examined in this study, such as nuclear-related interruption of local command and control.

- The use of nuclear weapons on the battlefield affects subsequent maneuver and should be considered during planning. In the past, ideas about use of nuclear weapons in support of battle have focused on using conventional forces to canalize the enemy into a lucrative nuclear ambush. Perhaps nuclear effects on terrain can be exploited so that nuclear weapons can be used to canalize enemy forces into a conventional ambush.

- Troop safety constraints, which are observed by both sides, create a situation where hugging the opposite side's maneuver forces effects a nuclear sanctuary of sorts. This could lead to several interesting tactics; one, for example, is a stronger conventional force maintaining close contact with a weaker defender to minimize the defender's opportunity to use its own nuclear weapons.

- The effectiveness of nuclear fires is not necessarily directly correlated with the number of weapons detonated (or the gross number of kilotons expended). In these simulations, the red force's massive use of nuclear weapons was singularly inefficient. Blue nuclear weapon use, while far fewer in quantity and yield than red, generally caused fifteen times the number of combat losses per kiloton expended (although this is less a commentary on good blue nuclear use than on poor red use). Red nuclear fires were predominantly templated; focus was on attacking nuclear delivery units by assuming where they would be located—in effect, massive terrain fire. Red force players did not use tactical intelligence available to them to their maximal advantage.

- At least for the scenario examined here, the often stated claim that NATO forces would be worse off after a comparable nuclear exchange than they would have been if nuclear weapons had not been used is not correct. Results showed that compared to <u>no</u> nuclear use, blue forces did not fare worse than when nuclear weapons were used, <u>even</u> when the exchange was not comparable (a massive red strike compared to the blue strike).

Notes:

[1]Janus 4.02 is a stochastic, two-sided, dynamic, high-resolution, computer simulation of combat. The Janus combat model was developed at the Lawrence Livermore National Laboratory. For more information, see the Janus Users Manual: Wolfe, S.E., *The Janus Manual*, M-226, Lawrence Livermore National Laboratory, January 1988.

[2]To introduce nuclear play into the scenario, it was necessary to develop a plausible rationale justifying the use of nuclear weapons by the blue force. Red use of nuclear weapons, if any, would be in reaction to blue use. The rationale developed follows: In anticipation of the loss of significant forces during the critical corps counterattack, the corps commander requested and received authority to execute a SEP during a 12-hour time window beginning at H+30 hours. The trigger condition that would authorize nuclear use would be loss of a specified amount of combat power. At H+34 hours, corps losses met the trigger condition. Execution of the SEP throughout the corps area of responsibility was ordered. For this study it was assumed that the SEP was executed beginning at H+35 hours and was devised to defeat first echelon armies and delay second echelon armies, but only the portion of the SEP directed against first echelon army units in the sector gamed were actually modeled.

[3]Some intelligence analysts have suggested that a possible Soviet reaction to a NATO use of theater nuclear weapons is to ignore it so as to be able to reap the political benefit (in the eyes of world opinion) by not responding in kind.

[4]During the course of a battle simulation Janus records data periodically (*e.g.*, unit positions, strength, remaining ammunition and fuel) and upon events (*e.g.*, artillery fires, nuclear detonations, conventional kills). From these records common MOE can be extracted easily. The data also can be examined extensively at one's leisure using the Analyst Work Station (AWS), a computer tool developed at the Lawrence Livermore National Laboratory that enables one to postprocess simulation data with great flexibility. Battles can be reviewed as "movies" and causal hypotheses can be tested. For example, AWS can help an analyst to quantify the effectiveness of artillery coverage of river fording sites or minefields in several dimensions: number and type of rounds fired, impact patterns, kills, delays, *etc.* Using this tool the analyst can identify more clearly cause and effect relationships and synergistic effects removed from the charged atmosphere surrounding a game in progress.

#142

TITLE: A Macro-Level Tank Attrition Analysis

AUTHORS: LTC Robert M. Baker and Mr. Kenneth Mobley

ORGANIZATION: HQ TRADOC Analysis Command
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ABSTRACT:

This study is a macro-level analysis in response to a question the CG, TRADOC, posed to the analytical community..."How many times do I have to kill a tank"? The question implies concern that the design of our anti-armor force structure may depend on overlapping requirements generated by a series of independent analyses of different families of anti-armor systems. This analysis uses some simple analytical tools to provide graphic decision aides for examining trade-offs among generic anti-armor systems in terms of doctrine, force design requirements, system acquisition policies, and risk acceptance. An innovative methodology quantitatively depicts the relationships among the line-of-sight battle, the non-line-of-sight battle, and Soviet decision making at the operational level of war. Specifically, the study develops the ratio of <u>acquired</u> anti-armor capability to <u>required</u> capability for six different combinations of doctrine, force design and system acquisition strategy. In general, the results provide quantitative support for AirLand Battle doctrine. Beyond the study results, the methodology represents an analytical structure which may be useful to others in examining force design issues at a macro-level. The methodology is not model dependent. Although a background scenario is necessary, it can be changed easily to explore other postulations.

PAPER IS CLASSIFIED
REQUESTS FOR INFORMATION SHOULD
BE DIRECTED TO ORIGINATING AGENCY

#179
TITLE: Logistics Force Design Alternatives

AUTHOR: R. McDowall

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ABSTRACT:

The Logistic Force Design Alternatives Study is a Concepts Analysis Agency initiative to analyze the methods of allocation that are used to develop the support forces necessary in a theater of operations. Functional area analysis combined with the modification of the methodology currently utilized to develop the support forces in a combat simulation will be used to develop alternative procedures for force development.

NO PAPER PROVIDED

#178

TITLE: Logistics Force Planner Assistant

AUTHOR: James J. Connelly

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ABSTRACT:

Logistics force planning addresses the type and composition of support units needed to sustain and maintain the units in the Army combat force. Microcomputers technology, using knowledge processing software, can assist in the management and conduct of this planning. Based on these technologies, an assistant (LOG PLANNER) has been developed to support the logistics planning activity conducted by the Office of the Deputy Chief for Logistics, as part of Total Army Analysis (TAA). In support of the TAA process, two basic types of LOG PLANNER assistance have been defined. One type provides the user with analytic and coordination procedures associated with the conduct of the TAA process. The other type provides for user access to and update of files summarizing the force issues arising during the TAA process. The implementation of the LOG PLANNER is described and the results of the evaluation of the system in a series of user trials is presented.

NO PAPER PROVIDED

#175
TITLE: Critical Factors in Determining Combat Service Support Requirements

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ABSTRACT:

An analysis is made of the effect of changes in input data on the generation of nondivisional support force structure for a given combat force as modeled in the Total Army Analysis FY 96 (TAA-96) study. The model used to determine the generation of support force structure for the TAA Study is the Force Analysis Simulation of Theater Administrative and Logistics Support (FASTALS) Model. The FASTALS Model determines the size and composition of the support forces required to sustain a given combat force. The model is primarily used in force planning analysis to determine balanced, time-phased, geographically distributed force requirements.

NO PAPER PROVIDED

FORCE BUILDER DECISION SUPPORT SYSTEM: AN OVERVIEW (U)

By

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INTRODUCTION

A new decision support system is being developed in the Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS) called Force Builder. Force Builder is being implemented under the direct auspices of the ADCSOPS for Force Development and Integration by the US Army Force Integration Support Agency (USAFISA). Force Builder comes at a critical juncture in the Army's history, a time when the requirement for improving force integration has never been more pressing.

Today, through a sequential Total Army Analysis (TAA) and Force Integration Analysis (FIA) process, there is limited opportunity to look at force alternatives and to consider the effects of changes in force structure and resource levels on warfighting capability. The critically important mission of supporting the warfighting Commanders-in-Chief (CINCs) through the fielding of combat-ready units, is hampered by the complexity of the processes and the quality of the data involved. Furthermore, the sequential character of today's processes, without the ability to conduct fully integrated (i.e., simultaneous consideration of warfighting, structure, and resources) analyses, calls for development of a powerful tool to help get the job done -- the Force Builder Decision Support System (DSS).

This paper provides an overview of the background and objectives that led to the Force Builder DSS, a view towards the objective system with specific discussion of current force management applications and modeling developments to date, and a summary of the priority areas of concentration in the development effort. The evolving Force Builder DSS will provide a useful umbrella topic for many issues of direct and immediate importance to the Army's operations research and analysis community. Future papers will address these issues and the approaches being used in Force Builder to solve them.

BACKGROUND

The surge of major materiel system modernization in the late 1970s and early 1980s exacerbated an already fully-challenged US Army. The problems varied from planning to documenting the new weapon systems in new organizations, to "synchronizing" procurement with the personnel training for the new systems, to the subsequent fielding and sustainment of the modernized Army. Although these functions were not new to the Army, maintaining the current fighting force while simultaneously transitioning so many modernized systems and organizations complicated the Army's primary objective -- to provide combat-ready units to the warfighting CINCs. Today, the force integration challenge has not lessened in intensity.

Recognizing the severity of the problem, the Department of the Army Inspector General (DAIG) was tasked to conduct an Army-wide investigation of the management processes which impacted on major equipment force modernization. Completed in FY82, the investigation results reported two principal findings: (1) there were extensive documentation and execution problems in force modernization; and (2) there was a lack of knowledge at all levels of how the Army really operates.

A follow-up inspection of force integration in 1986 by the DAIG found that many of the problems surfaced in the initial inspection had been corrected. However:

- comprehensive guidance for force integration of HQDA still did not exist;

- HQDA was still not organized to manage force integration effectively;

- HQDA staff agencies that should be involved in integrating doctrine, force structure, and equipment were still focusing on the fielding of weapon systems and major end items, and not on units and organizations; and

- no agency/authority below the Vice Chief of Staff of the Army (VCSA) had responsibility for force integration. The VCSA approved the follow-up inspection findings and designated the Deputy Chief of Staff for Operations and Plans (DCSOPS) responsible for force development and integration.

The efforts of the DAIG detailed earlier provided some of the impetus to articulate more thoroughly the overarching concepts that guide the process today, and also the requirement for an FD&I support system like Force Builder. Within the Army Secretariat and the Army Staff, significant efforts were underway at the same time which began to move Total Army force structure/resource management toward a broader front.

Central to those efforts was an evolving concept which identified all Army activities as falling into four major mission areas: (1) systems acquisition and fielding; (2) installation operations and facilities (i.e., base operations and real property maintenance activities); (3) Tables of Distribution and Allowances

(TDA) missions (i.e., the infrastructure missions like depot supply and maintenance, training, and health services); and (4) Tables of Organization and Equipment (TOE) missions, the combat forces. The major thrust of this categorization was to get standard, consistent, rational treatment of all resources (dollars, people, facilities, equipment, goods, services and time), and to establish the basis of the functional interrelationships in the PPBES structure -- from plan to program to budget to execution. This led to the restructuring of the Army's program into Management Decision Packages (MDEPs). MDEPs were created from Program Development Increment Packages (PDIPs) which covered the program years, and the Budget Increment Packages (BIP) which covered the prior, current and budget years.

As shown in study after study, there needs to be a common framework in which the horizontal and vertical integration of the Planning, Programming, Budgeting, and Execution System (PPBES) and force structuring can take place. Analysis of the contributing processes reveals serious disconnects among data source inputs, processes, and outputs. Numerous activities over the past several years have gone a long way towards correcting data and process deficiencies and inconsistencies, and to develop needed capabilities to achieve the necessary integrated approach.

The ODCSOPS continues to work on the force modernization challenge discussed at the beginning of this section. Specific issues being addressed are: how does the Army (1) distribute the most modernized assets and redistribute existing assets based on wartime deployment assignments; (2) ensure compatible organic and higher echelon combat service support; and (3) minimize unit/force turbulence. An integrated force packaging/modernization methodology becomes essential if these goals are to be achieved.

It is in the force development and integration process that the warfighting requirements of the CINCs that produce the "demand" for specific types of structure and composition are addressed. Those structures and composition must be "supplied" (resourced) with soldiers and civilians, equipment, facilities, and funds. The process must be improved to really integrate those resource supplies with force structure demands to produce the "best affordable, supportable, and deliverable" US Army fighting force for the CINCs. This force product is at the center of Force Builder development objectives.

OBJECTIVES

The principal objectives of Force Builder are:

- Develop and monitor status of the force structure throughout the PPBES. This means that the near-term structure through the budget force must be evaluated for supportability by focusing on available inventories (on-hand or due-in) from the resource pipelines (e.g., people, equipment). The structure beyond the budget year in the force development plan must be assessed by focusing on available dollars. In all years it is essential that the "value" of the force be measured. This means that the combat capability of the force be assessed continuously in conjunction with the affordability/supportability of the force.

- Provide authorization documentation guidance to:

  - allocate resources down to organization, and

  - to support reporting back through the chain-of-command (through Major Commands -- ITAADS/VTAADS to HQDA -- TAADS and ultimately TAADS-R).

- Support execution monitoring and special queries of resource status in the execution phase, to include personnel, equipment, training, and Operations Plans (OPLANs).

- Provide timely, rational, force-related, alternative growth/retreat paths (<u>the</u> prioritization scheme) for multi-year resource adjustments so that they:

  - span all relevant years of the PPBES in Management Decision Package (MDEP) structure;

  - reflect revised resource allocations that are doctrinally correct, properly integrated, and complete; and

  - depict warfighting capability changes.

- Provide the capability to move quickly to the "management margin" when only a small aspect of the force is affected by change.

- Establish a "what-if" capability to provide rapid responses to questions about warfighting capability, force structure, and resources.

- Access the Army's controlled data environment for sharing authoritative force structure and resource data.

- Support Army data management policy.

- Present information quickly and in an easily understood manner within the Army and through ODCSOPS to the CINCs, other Services, the Office of the Secretary of Defense (OSD), and the Congress.

- Provide executive summaries of changes (personnel and equipment authorizations) that will constitute the guidance for the documentation system.

- Be <u>the</u> decision support tool for organization/force integration.

THE OBJECTIVE SYSTEM

In the previous sections, current Army force structuring and resourcing processes were described and assessed, and objectives for the Force Builder DSS were listed. In this section, the objective Force Builder DSS is described.

Force Builder will use a single, integrated methodology to support both force development and force management activities. Force development encompasses the deliberate process of developing a modified force that integrates CINC warfighting requirements and is linked specifically to the program and budget, producing both summary documentation guidance and inputs to the functional area prioritization and planning processes. Force management includes the day-to-day adjustments to the existing force, resourced in the budget, in response to force execution monitoring.

An overview of the improved Army force development and integration process with Force Builder is shown in Figure 1.

The process begins with a consolidated set of defense strategic, fiscal, doctrinal, and operational guidance. The ODCSOPS will propose concepts to meet the guidance requirements. Force Builder will be used to evaluate these concepts using the current force structure as the baseline. Once a set of structure concepts have been determined to be in the acceptable zone for warfighting capability and in the feasible zone for resourcing at the macro level, and reviewed by the staff, Force Builder will be used to perform detailed analyses to determine that the selected structure alternatives can, in fact, be manned, equipped, housed, sustained, mobilized, and deployed in accordance with CINC OPLANs.

The major alternatives will be reviewed in detail by the functional staff proponents, reworked in Force Builder as necessary, and then presented for decision/guidance to the Army leadership as the "right" Army position. This position will the new Army Force Development Plan (AFDP) which will be the basis for the Army's program and budget submissions to OSD in the FYDP/PPBS process. This same process can be used to yield rapid response answers to "what-if" questions. Results can be passed forward to the CINCs, OSD, the Congress, and others to evaluate and use to influence future defense guidance and operational, mobilization, and contingency plans.

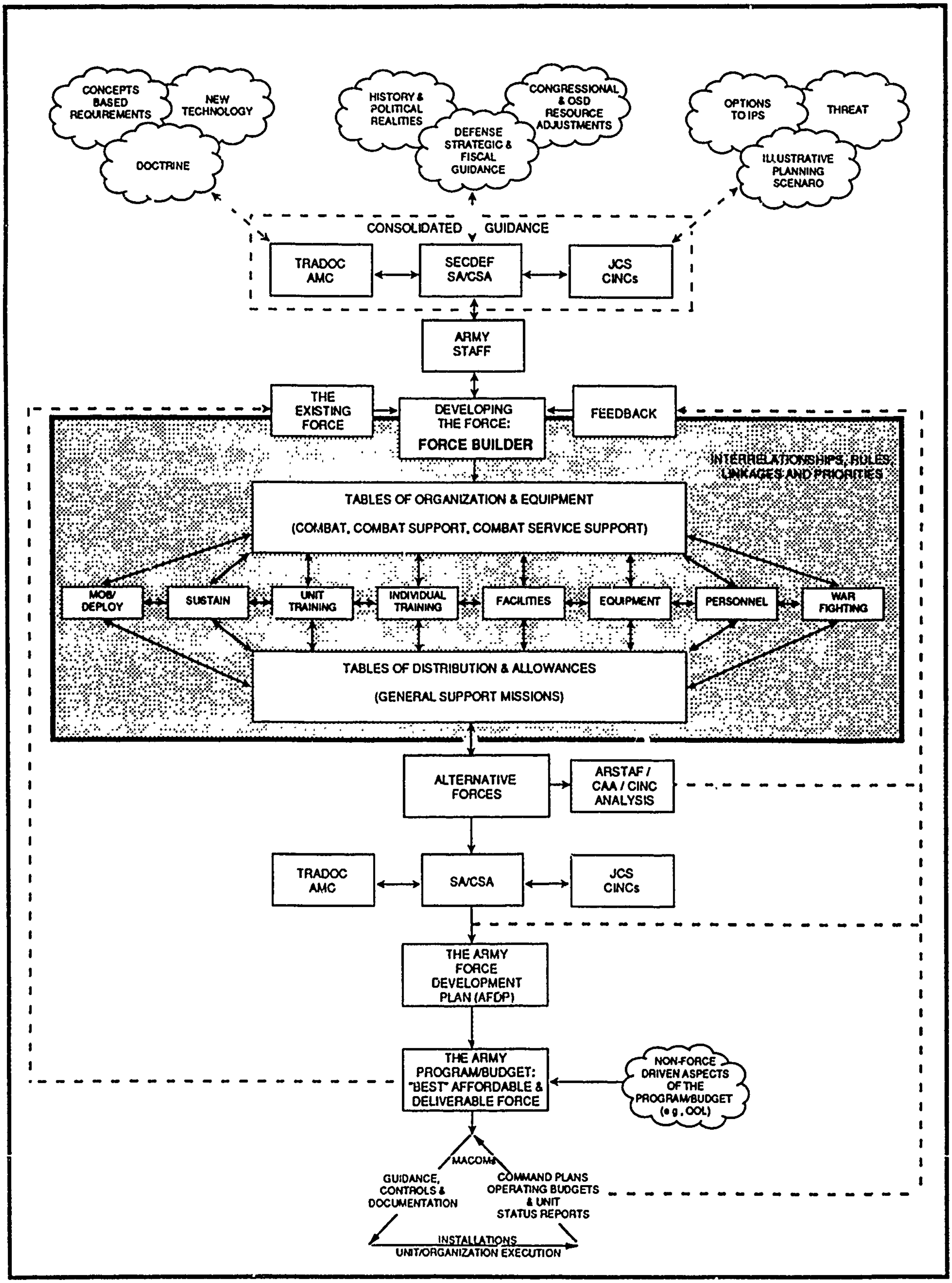

Figure 1. Integrated Methodology

The Force Builder objective system is being developed through a two-pronged approach: (1) Force Management Applications, and (2) Force Models. The Force Management Applications are keyed to providing immediate support to Action Officers involved with current processes, such as Force Integration Analysis. The Force Builder models are being developed more slowly, because the processes to be captured are significant and complex.

FORCE MANAGEMENT APPLICATIONS

In the near term, Force Management Applications (FMA) are providing the early analytical power and capabilities to the Force Builder community. The primary emphasis is on the development of those special applications that provide capabilities that are compatible with the development of the models.

The first FMA being built is the Force Integration Analysis (FIA) application. The Force Builder implementation of FIA will provide ODCSOPS Action Officers -- Organizational Integrators, System Integrators, Force Integrators -- with the capability to query the mainframe computer about the status of a unit or a set of units of interest. It provides the same level of functional support as provided by an earlier PC-based system as well as easing the problems of dataloading, access by users, and synchronization of data.

The overall thrust for Force Integration Analysis is to determine the executability/supportability of the force by answering such questions as:

- Can the force be equipped? Is the equipment already in the budget and program correct by Line Item Number (LIN) to support the equipment requirements of the force by year?
- Can the force be manned? Is the predicted mix of personnel, by component/grade and skill, what is needed for the force?
- Can the force be trained? Do ammunition, procurement spares and stock-funded repair parts in the pipeline support the projected unit training levels each year? Do TRADOC and Reserve Component (RC) schools have the capability to support individual training requirements?
- Can the force be sustained? Are spare parts and depot maintenance output available to support desired operating tempo (OPTEMPO)?

The current database interfaces to the FIA module are the Force Accounting System (FAS), the Total Army Equipment

Distribution Program (TAEDP), the Unit Status Report (USR) and OPLAN data. In the future, additional information will be added from The Army Authorization Documents Systems (TAADS) and from the Tables of Organization and Equipment (TOE) about equipment and personnel (MOS and grade level) requirements and authorizations.

Beyond FIA development, a significant number of Force Builder special applications will be employed to perform status reporting and execution monitoring. They will be used to compare such data as the Army Force Development Plan (AFDP) to the "actuals," such as the USAFAC 218 report for dollars and TAEDP for current equipment on-hand, that will show how the AFDP is being executed. These applications will identify disconnects between planned and actual positions on such things as personnel and equipment distributions, for example, and will provide some insight as to the reasons for disconnects and for identifying means to resolve these problems. This information will also provide necessary feedback to the overall Force Builder process to insure checks and balances are present in the "loop." Status reporting of relationships will be another area of concentration, examples are command and functional "tree" relationships.

In a similar manner, some special applications will be used to develop and analyze new data sets that will be used by the Force Builder models. In some cases, the results of execution monitoring analyses will result in a "scrubbed" data set that might be appropriate as an input to the models. In the ideal case, the data scrubbing aspects of Force Builder are expected to be limited to the near term. It is hoped that use of the Force Builder integrated methodology coupled with use of authoritative databases will lead to fewer requirements for significant data scrubbing efforts in the future.

MODELING APPROACH

The Force Builder modeling approach is built around the concept of developing a macro-level, quick turnaround definition of a doctrinally sound (based on Army structure rules explicitly defined in the methodology), affordable, sustainable, deployable, and combat effective Total Army force structure. This is followed by a very detailed micro-level definition and analysis of the force. The focus of the methodology is always at the Total Army level, while considering the theater-specific orientations and characteristics of the pieces of the Total Army based on the scenarios being considered during the exercise of the methodology.

Force Builder starts with an "objectively" designed force structure for the Total Army focusing on multiple years. It is objectively designed in that it incorporates significant analytical techniques qualified by expert military judgement, as opposed to being designed primarily by subjective means and supported by only a few quantitative analyses. Next, the approach presents multiple force "alternatives." Then, estimates are made of the "real" combat capabilities of the force and those estimates are verified via a detailed CAA OMNIBUS-type analysis. Following this, a doctrinally sound deployable Army "tail" is developed while considering the impact of the "tail" on combat capability, but without automatically "hollowing" it out. The force is analyzed quantitatively as part of the POM development while considering the impacts on capability, sustainability, affordability, and deployability of the force via an integrated, synchronized process represented within a system of models. Finally, except for the combat simulation at CAA, the process takes hours to a few days to complete a single cycle (the development of one alternative at the most detailed level of definition). The macro-level definition of an alternative Total Army force structure with estimates of warfighting capability, affordability, sustainability and deployability will be available in a matter of a few hours. The TAA process modified by Force Builder's integrated methodology provides the Army with the opportunity to: (1) complete a better Total Army Analysis sooner (days rather than months), (2) have a continuing process available to respond quickly to the changing program/budget environment, and (3) provide the common mechanism for the HQDA staff to communicate these changes and impacts on the force structure in order to develop truly coordinated Army decision positions.

Today, the Army accomplishes force integration analyses through a subjective process. Force Builder is intended to capture the best parts of that subjective process, including models and other tools, and provide a "working methodology" that provides integrated analytical support. The hierarchical set of interrelated models shown on Figure 2 on the following page captures the approach described above.

SUMMARY OF IMPROVEMENTS

The most significant benefit to be achieved with Force Builder will be the availability of an automated, integrated methodology that will assist force developers at all levels. It will specifically assist the ODCSOPS in fielding integrated, coherent force packages that are internally capable (can participate in joint/combined operations) and executable. Other significant improvements to be achieved through Force Builder are listed below.

- CINC OPLANs and priorities will be better integrated into the force development process.

- The TAA/FIA process with Force Builder will be substantially improved through the use of an integrated methodology with maximum staff participation.

- The TAA/FIA processing cycle with Force Builder will be significantly shortened (from two years to several months), providing more time for direct/iterative dialogue with the CINCs.

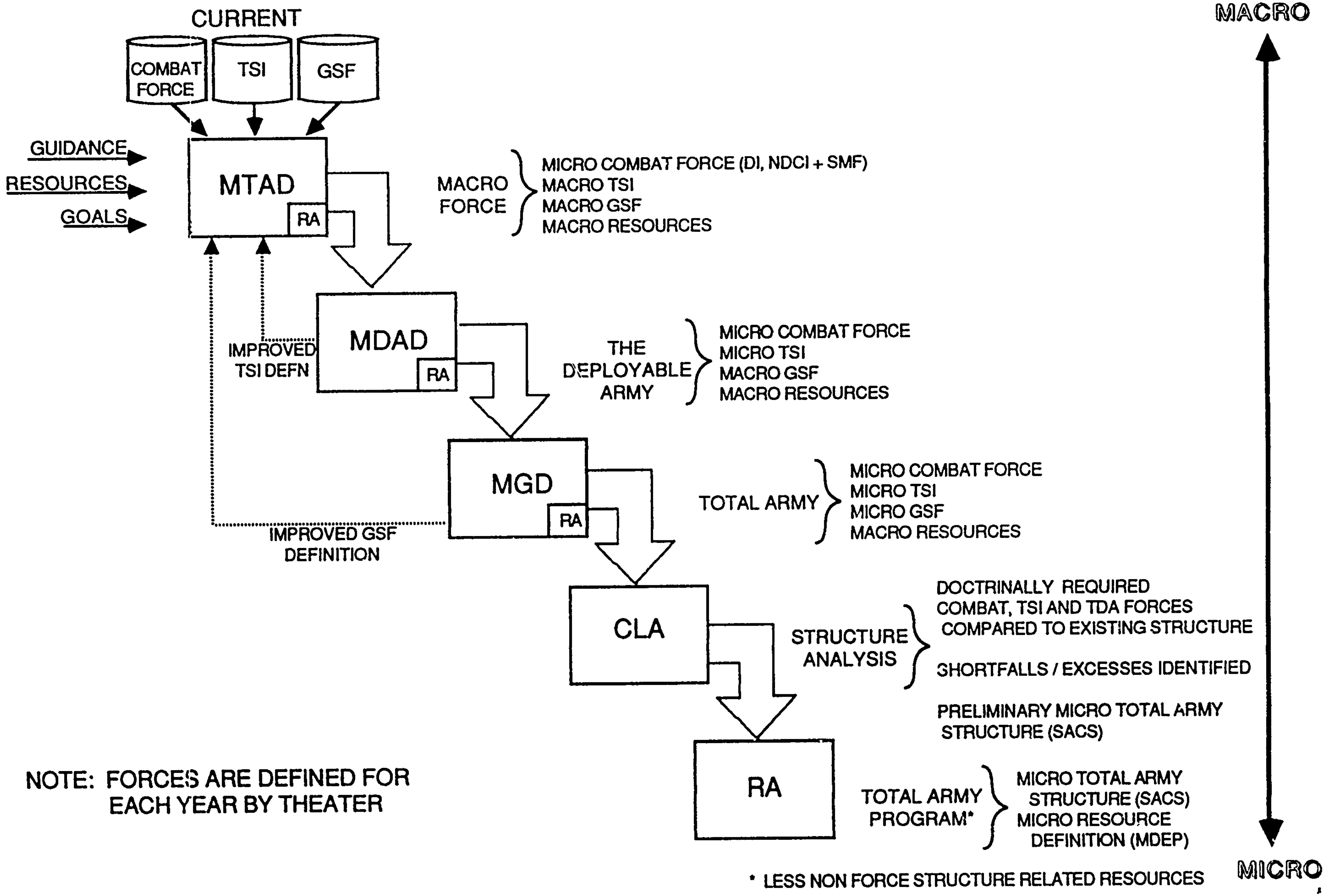

Figure 2. Force Builder Cascading Models

- The shortened processing cycle will make more time available for discussion of force structuring rules, assumptions, and priorities.

- The TAA/FIA process with Force Builder will allow CAA more time to conduct critical combat effectiveness analyses of structure alternatives.

- Force Builder will generate timely, affordable authorization statements for equipment and personnel which will reduce the burden on the functional area processes and allow force structure to drive personnel, materiel, and facilities resource allocations.

- Force Builder's execution monitoring capability will provide direct feedback to the force development process, ensuring that the process always begins with an accurate picture of the current force.

- Force Builder will enhance the functions now performed by FAS/SACS and improve the documentation guidance to TAADS.

- Force Builder will generate recommended program/budget mission essential acquisition requirements that are linked directly to force structure requirements.

- Force Builder will provide a better mechanism for integrating unit priority and readiness guidance into the force development and execution processes.

- Force Builder will provide timely, integrated information to the force management process.

As reflected in the objectives for Force Builder and reemphasized here, the Army must have a force development and integration process that:

- is based on an integrated methodology that considers CINC warfighting requirements, force structure, and resources;

- produces feasible, alternative force structure options to meet changing mission requirements and resource constraints;

- explicitly considers the affordability and deliverability of the force alternative as part of the feasibility determination; and

- is able to respond to the formal and informal information requests with the "about right" answer in the time required.

The absence of a functioning and disciplined integrating methodology and supporting tools guarantees decisions that are not adequate to the challenges faced by the Army today. Force Builder provides the mechanism for meeting these challenges directly.

#165

TITLE: Impact of Current Stockage Policy and Procedures on Provisioning Cost and Weapon System Operational Availability (Ao)

AUTHORS: D. Shaffer and R. McGauley

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ABSTRACT:

Over the past two years AMSAA has increased its quantitative analysis efforts on the adequacy of the Initial Provisioning Packages which are established for major systems prior to fielding. These analyses have been in support of the independent evaluation prior to materiel release. The results have raised serious concerns over the current stockage policy, the implementation of the policy by PMs and the process of reflecting actual test results in update of required provisioning.

The Army's Supply System has largely been based on demands for repair parts which are actually experienced in the field. When demands for an essential item reach a certain level, an item can be added to the PLL/ASL and then retained as long as demands continue to materilize. While most criteria, items on the ASL/PLL have been stocked becaused they were the aboce demand criteria, there are also other classes of "non-demand" items. For example, when a new weapon system is introduced to the Army, initial stockage is prescribed by the Support List Allowance Card (SLAC). Items are selected for inclusion on the SLAC if it is anticipated that they will meet the demand criteria. Another group of nondemand supported items which reside on the ASL is known as the Mandatory Parts List (MPL). These items also do not meet the demand stockage criteria, however, are required either because of their combat essentiality or are required to maintain the desired levels of operational availability. AR 710-2 places several limitations on the use of MPLs.

Consequently, a system exists which largely does not efficiently stock to achieve the availability goals of the Army's weapon systems. Furthermore, readiness goals are not considered until after the demand-based strategies are considered and then only on an exception basis through the MPL process.

ARMY MOBILIZATION INTEGRATION CELL (AMIC)

Don Spigelmyer

Engineer Studies Center

INTRODUCTION

This is our second annual state of the union address on the AMIC. Last year we discussed three major goals of the Army Mobilization Integration Cell (AMIC). They were: Mesh senior leadership mobilization concerns with analytic and research efforts; Facilitate sharing of mobilization information; and Provide a focal point for mobilization study efforts. Since that time, these goals have been refined based upon experience gained through working in the mobilization arena. Currently, they are:

GOAL # 1–FACILITATE SHARING OF MOBILIZATION INFORMATION

GOAL # 2–INTEGRATE MOBILIZATION CONSIDERATIONS INTO HOW THE ARMY RUNS ON A DAILY BASIS

GOAL # 3–FOCUS ANALYTICAL COMMUNITY ON KEY MOBILIZATION ISSUES FACING THE ARMY

This paper addresses each of these goals separately. It discusses AMIC's efforts to meet these goals over the past two years and describes what remains to be done. Two things I can tell you up-front. First, the AMIC has come a long way in understanding and addressing these issues/goals. Second, the more we understand--the more we realize how much is left to do!

BACKGROUND

Since 1983, the Deputy Under Secretary of the Army for Operations Research (DUSA-OR) has conducted an annual series of workshops designed to make sure that the studies and analyses conducted by the Army are focusing on critical issues. The workshops are part of the Issue Assessment Process (IAP). They are conducted under the auspices of the Study Program Management Agency (SPMA), and they strive to bring order out of what could easily become a random allocation of studies and analysis effort.

Back in 1985, the IAP identified "mobilization" as one of those critical topics that needs more focused analytic support. As a result of this decision, the DUSA–OR and the Chief of Engineers signed a Memorandum of Understanding which tasks the Engineer Studies Center (ESC) to spend between two to five work years of effort per year over the next three years developing a process which will focus the analytical community on senior leadership mobilization concerns, and facilitate sharing of mobilization information. In other words, ESC will help SPMA assure that mobilization studies address topics of high payoff, avoid duplication of effort, and receive high visibility while researching considerations. As mentioned earlier, this initiative is termed the Army Mobilization Integration Cell (AMIC). The SPMA is funding this program and serving as the project sponsor for administrative matters. The Deputy Chief of Staff for

Operations and Plans (DCSOPS), Mobilization Division (DAMO-ODM) is serving as the functional area sponsor. DCSOPS is the DA Staff proponent for mobilization, and as such must play a role in any mobilization-related project that is to succeed.

The AMIC is essentially a pilot program by which the DUSA-OR can determine whether such focused allocation of analytic resources can shore up weaknesses in DA's analytic program. Depending on how well this concept works for mobilization, DUSA-OR can be expected to follow the same approach for other critical problem areas as identified by the IAP.

ESC began functioning as the AMIC in December 1987. Since that time, ESC has had between three to four analysts dedicated to AMIC at all times. These analysts have been intensively researching, analyzing, and communicating on the subject of Army studies in support of mobilization.

GOAL # 1
FACILITATE SHARING OF MOBILIZATION INFORMATION

During the past two years, AMIC found a disturbing lack of coordination between mobilization planners. In many cases, we found planners who sat across the hall from one another in the Pentagon and had no idea what each other was doing. I'm sure this doesn't come as a great shock if you've ever been assigned to the Pentagon. However, these planners had separate contractors working on the same problem and no one was communicating with each other. These situations led to duplication of effort and wasted dollars. There was no lack of examples of this nature. Listed below are the three major information shortfalls we identified through interviews, a survey of 130 mob planners, and a series of overall and functional mobilization seminars. The AMIC initiative to improve each shortfall is listed after each issue.

SHORTFALL: Lack of knowledge of who else was working mobilization issues, where they were located, and what they were working on.

INITIATIVE: Develop a Mobilization Point of Contacts (POC) directory.

AMIC gathered the information and published a Point of Contact (POC) Directory which contains mobilization planners in Department of Defense (DOD), Joint Chiefs of Staff (JCS), Department of the Army (DA), and Army major commands (MACOM). Also included in this directory is a listing of mobilization planners in all non-DOD civilian government agencies. This portion of the directory was prepared in coordination with the Federal Emergency Management Agency (FEMA). The directory contains the name, organization, address, and area of concentration of the mobilization planner. The directory is indexed three different ways--by name in alphabetical order, by organization, and by area of concentration. This directory provides the planner with a tool to determine and locate other planners and organizations working on similar mobilization issues. This, in turn, should help improve coordination and reduce duplication of effort. AMIC will update this directory and publish it one more time prior to the termination of the project. We will also make a recommendation for some other organizational element to assume this responsibility, either contract or in-house.

SHORTFALL: Lack of awareness of central data repositories and how to utilize them to identify previous mobilization study efforts. DOD has two data repositories created for the express purpose of providing literature search services in conjunction with their data bank functions. These are the Defense Technical Information Center (DTIC) and the Defense Logistics Studies Information Exchange (DLSIE) center. These central repositories enable the planner to query central data bases to find out what studies/models have been completed or are ongoing on a particular topic for any specified period of time. If required, the planner can then obtain either the entire report or an abstract of any appropriate study and/or model. This, in turn, enables the planner to build upon the analytical efforts that have already taken place, thus reducing duplication of effort. On an AMIC survey of 114 POCs involved in the mobilization planning arena, many planners were unaware of the central document repositories. The following chart quantifies these insights.

		AWARE OF	
MACOM/AGENCY	# OF POCs	NEW STUDIES	CENTRAL REPOSITORIES
HQDA	55	34 (62%)	32 (58%)
FORSCOM	23	13 (57%)	4 (17%)
AMC	14	10 (71%)	9 (64%)
TRADOC	12	10 (83%)	1 (8%)
OTHER	10	6 (60%)	3 (30%)

INITIATIVE: Publish a listing of mobilization studies completed over the past 10 years and educate mobilization planners on the use and benefits of the DOD central data repositories. In coordination with DTIC and DLSIE, AMIC recently completed a major research effort to compile, publish, and distribute a listing of mobilization studies completed over the past 10 years. For the most recent 5-year period, this listing contained an abstract for each study and information on who conducted and who sponsored it. For the remaining 5 years, it provides a title listing and information on the sponsor and performing agency. The 10-year listing contained over 1,500 mobilization studies. It provides the mobilization planner with a powerful reference tool. It enables the planner to quickly research analytical efforts that have already been accomplished on the issues he or she is working. This helps resolve issues quicker, provides a wealth of data, and precludes "reinventing the wheel." AMIC intends to provide an annual update of this report during its tenure and will recommend a continuation by DTIC and DLSIE at the termination of the AMIC charter.

In addition to providing mobilization planners at the DA and MACOM levels the 10-year studies listing, the AMIC sponsored a series of presentations on the use and benefits of the DOD central data repositories. These briefings were provided to mob planners at AMIC sponsored seminars throughout the past year. The intent was to encourage use and get mobilization planners signed up to receive current awareness bulletins from DTIC and DLSIE. These bulletins inform the planner when any new mobilization study is initiated.

SHORTFALL: Lack of awareness of existing mobilization training, recurring conferences, and organizations. AMIC discovered through interactions with mobilization planners that many of them have no formal training in mobilization planning. In many instances, they are not aware of training opportunities that exist. They are also unaware of many recurring seminars and conferences that address mobilization planning issues. They are not aware of what is going on outside of their own organization. All of these factors lead to a less than effective planner.

INITIATIVE: Research and publish a handbook which describes mobilization training available. Include in this handbook sections which describe: DOD and non-DOD organizations involved in mobilization planning, recurring conferences and seminars which deal with mobilization, a description of mobilization exercises and POCs to obtain after-action reports from, and DOD and non-DOD mobilization training opportunities. AMIC is in the process of developing this handbook. This project is in the research phase and should be published in draft form by the end of the calendar year.

GOAL # 2
INTEGRATE MOBILIZATION CONSIDERATIONS INTO HOW THE ARMY RUNS ON A DAILY BASIS

One of the primary observations made by AMIC is that mobilization planning is usually done separately and many times as an afterthought. In many cases, the mobilization planner is separated from the rest of the staff (usually located in the basement) and is only called upon during required exercises. At that time, he or she is responsible for evaluating mobilization implications for the entire functional spectrum of their organization. Sound familiar? Army organizations at all levels get so involved in day-to-day peacetime operations that they forget their primary purpose of deterring aggression and being prepared to fight, if necessary. Most peacetime operations will still be required during a conflict only faster and more frequently. Therefore, it is incumbent upon us to consider and plan for these operations under a wartime scenario. It is our belief that if the Army is going to be able to function effectively during wartime, it must prepare for it during peacetime. AMIC has taken upon itself the mission of trying to integrate mobilization considerations into three limited areas:

* STUDIES AND ANALYSES
* FORCE DEVELOPMENT
* SYSTEMS DEVELOPMENTS AND ENHANCEMENTS

STUDY INTEGRATION. In order to integrate mobilization considerations into the Army studies program, AMIC had to work through the SPMA. This organization is responsible for managing the AR 5-5 studies system. SPMA works with the ARSTAFF and MACOM Study Coordinators in screening potential study/analytical efforts for approval and funding under the AR 5-5 program. Our intent was to get the various ARSTAFF and MACOMs to consider mobilization requirements or impacts in all study requests. If a study proposal did have an impact on mobilization, the scope of the study could then be expanded to address this impact.

This approach is in contrast to an organization submitting a study proposal and then after the study is complete realizing that it does not address wartime/mobilization requirements. At this point, a follow-on study has to be initiated or wartime requirements are simply ignored. AMIC's approach to addressing this situation was to develop a list of mobilization considerations to be used prior to submitting a study request. We then asked the SPMA to include these considerations as part of the AR 5-5 submission process. In essence, this approach requires all ARTSTAFF and MACOM Study Coordinators to examine each study submission and determine if the project has mobilization impacts. If that is the case, they are asked to expand the study scope to address the mobilization impacts. Hopefully, this precludes the need of submitting a separate request to address wartime requirements. In addition, it integrates mobilization considerations into the AR 5-5 study process. Listed below are the criteria that the SPMA agreed to include in the AR 5-5 process.

MOBILIZATION INTEGRATION CONSIDERATIONS

PEACETIME EFFICIENCIES VERSUS WARTIME REQUIREMENTS. Will it work in wartime/during a mobilization or is it primarily designed for peacetime? If primarily the latter, what will do the job in war?

GRADUATED MOBILIZATION RESPONSE. Can this system, method, or policy be applied in a situation less than full mobilization? Does it lend to a capability for incremented military and/or industrial expansion and improving our preparedness in times of tension?

JOINT AND COMBINED IMPACTS. What are the other service/allied nations impacts? Are joint or combined priorities considered? Who else uses it or will be affected by it? Who else do we depend upon and for what? Do we/would we provide it to others?

ADP INTEGRATION. Does it integrate with other supporting/related ADP systems in peacetime and in wartime? Is there already something out there that should be tied in to it? What about joint and combined requirements?

FOREIGN SOURCES. Where does it or its components come from? How dependable and vulnerable is the source? Are there alternative sources and/or items/materials? Impact of early loss of sources?

INDUSTRIAL BASE AND RAPID EXPANSION. How easy is it for the current and projected US industrial base to produce it? How easy is it to rapidly expand production? What critical materials and plant capabilies are involved? Could more relaxed "wartime" specifications (for example, a shorter service life) speed production?

CRITICAL MILITARY AND CIVILIAN SKILLS. What special skills are required to produce it, use it, and mai ? Will competing demands be created that affect other critical areas? What is the training time requirement versus training time realistically available?

DIFFERENT SCENARIOS. Where will it have to work? Europe-only scenario or several theaters at once? How does it fit in with more probable low-scale conflict (or short-of-conflict) involvement?

IMPACTS ON THE CONUS TDA SUPPORT BASE. How does it affect the TDA base in wartime/mobilization in addition to impacts on the TOE Army? Are TDA support aspects integrated vertically and horizontally in all systems?

NOTE: "It" may be a system, policy, procedure, item of equipment, or anything you are considering.

FORCE DEVELOPMENT INTEGRATION. AMIC's primary goal in the development of the force is to ensure that mobilization executability factors are an integral part of this process. One would think that this would automatically be done. However, this is not the case. Again, mobilization considerations often fall into the afterthought category. Under the current force development process, it appears that the primary concerns are the ability to operate and maintain the current force in a peacetime environment. Coupled with this is the desire to field new, modern weapons systems. Our ability to train, deploy, and sustain the current and particularly any larger force during war are secondary concerns. Peacetime operations and fielding new systems are the driving forces, not overall military strategy. Obviously, no one is suggesting that we not field modern weapon systems or ignore peacetime operating costs. What we are suggesting is that within budget constraints, we also consider our ability to mobilize both current and larger forces. This includes, not only evaluating our ability to deploy and sustain the current (and larger) force, but also funding requirements necessary to ensure this capability. It is essential that we have a balanced approach and that mobilization considerations are part of that balance. In an attempt to integrate this thinking into the force development process, AMIC has recommended to DCSOPS that mobilization executability requirements be added to: force development doctrine (FM 100-11), Force Integration Training (FIT), and Force Integration Analysis (FIA).

SYSTEMS DEVELOPMENT & ENHANCEMENTS INTEGRATION. Two unrelated events have led the AMIC to get involved with integrating mobilization requirements into systems development and enhancements. The first event affects almost everything we do. That being the advent of the computer age and our reliance on computers to support more and more of our planning. The second event is the loss of our institutional memory in actual mobilization planning. With few exceptions, mobilization planners from World War II are gone. Mobilization planners from the Vietnam War are rapidly disappearing from the government and military ranks. When these experts with actual experience are gone, there will be a serious lack of reality in the mobilization planning process. The best, and possibly the only, way to capture this expertise is to build it into existing and future mobilization models, data bases, and ADP systems. Unfortunately, we do not have the luxury of time to accomplish this task. There is an immediate need to utilize our remaining mobilization planners with actual experience to work with programmers to accomplish this. They need to work together to ensure that existing and future systems required during a conflict can function at all levels of mobilization as well as during peace. To put some teeth into this approach, AMIC has recommended that DA revise Army Information Management and Acquisition policy to ensure that mobilization considerations are included in the enhancement of current systems and the development of future systems. This would mean that before an organization would get funding for any changes to existing or future ADP systems would have to ensure that it can function at all levels of mobilization.

GOAL # 3 FOCUS ANALYTICAL COMMUNITY ON KEY MOBILIZATION ISSUES FACING THE ARMY

This goal was the driving force for creating the AMIC. AMIC was to serve as a test case for improving the analytical community's focus on the Army's most critical issues. Inherent in this goal is the need to examine the system, in being, which focuses the analytical community on critical issues, particularly mobilization. This system is referred to as the Army Study System and is defined as a series of interrelated events, organizations, and resources which provide study and analysis support to the Army. The Deputy Under Secretary of the Army for Operations Research is assisted by the Director of the Army Study Program Management Agency in providing oversight and direction to analytic efforts supporting the Army. We looked at the framework and context in which the Army's mobilization studies are accomplished. This entailed a review of pertinent regulatory guidance (AR 5-5 and DA Pam 5-5) and the systems flow with regard to the annual Army Study Program. As part of this effort, we met with the Army Study Program Management Agency representatives, attended work group sessions of the Study Program Coordination Committee (SPCC) and met with agency, ARSTAFF and MACOM Study Coordinators. The results of this analysis are too broad to cover in this limited report. Therefore, I will limit my discussion to 4 specific initiatives AMIC undertook to better focus the analytical community on key mobilization issues. These initiatives are:

ATTEND/CONDUCT SESSIONS WITH FUNCTIONAL STUDY COORDINATORS TO IDENTIFY PROPOSED MOBILIZATION TOPICS FOR FUNDING UNDER AR 5-5.

RESEARCH PROPOSED MOBILIZATION STUDY TOPICS IDENTIFIED TO PRECLUDE DUPLICATION OF EFFORT.

PRIORITIZE STUDY PROPOSALS IN COORDINATION WITH DCSOPS.

IDENTIFY ADDITIONAL STUDY PROPOSALS FOR FUNDING UNDER AR 5-5.

1. Attend/conduct sessions with functional Study Coordinators to identify proposed mobilization topics for funding. Our intent in this initiative was twofold. First, find out what mobilization studies the ARSTAFF and MACOMs were proposing for their annual study programs. Secondly, examine the process they used to identify and prioritize these study proposals.

Examining these goals in reverse order, we found that the process for identifying and prioritizing study proposals varied considerably. In most cases, it was not formalized. Usually, MACOM and ARSTAFF study coordinators obtained study submissions from subordinate elements at the last minute and left much of the prioritization to the SPCC Working Group sessions. These sessions are conducted by the SPMA prior to the formal SPCC where the fiscal year study program is finalized. These sessions are intended to review and prioritize the proposed study programs of all functional areas. It makes the process much harder when the submitting ARSTAFF or MACOM have not prioritized or coordinated their proposals beforehand. In almost all cases, literature searches (via DTIC or DLSIE) had not been completed. Without this step, there is no guarantee that the proposed study builds upon previous analytical efforts. This in turn, promotes duplication of effort and wasted dollars. It also precludes consolidating studies that could be combined into a single, more efficient analytical effort. Because of the "last minute" nature of many ARSTAFF and MACOM study programs, AMIC could not conduct coordination sessions with them. We could not even determine what mobilization studies were being proposed until they had all been submitted to the SPMA.

There were some notable exceptions to the above approach. Some agencies conduct internal coordination sessions as a means to spot and eliminate duplicative efforts and to assist in prioritizing planned studies. ODCSLOG does this at both the inter and intra agency level by means of the ODCSLOG Logistics Studies Steering Committee (LSSC). This committee is administered by the ODCSLOG Studies Coordinator and includes the logistics studies coordinators/representatives of TRADOC, Army Material Command, the Logistics Evaluation Agency, The Corps of Engineers, and miscellaneous other agencies and commands, on an "as invited" basis. It is this approach, with some slight modifications, that AMIC will recommend in AMIC's final report as a model for all ARSTAFF and MACOM study programs.

2. Research identified mobilization topics proposed for Army Study Program to preclude duplication of effort. Because of the "last minute" nature of study proposal submission, it was impossible for AMIC to research submissions for the FY 90 Army Study Program. Our initial intent was to determine how well the MACOMs and ARSTAFF were researching their study proposals prior to submission for approval and funding. From this type of research, we could get a feel for the amount of duplication of effort that existed. This would also indicate how well the program was building on studies previously accomplished. Since we could not have an impact on the FY 90 studies program, AMIC decided to conduct research on the FY 89 Study Program. We selected four topical areas of mobilization for review; Ammunition, Transportation/ Mobility, Casualty Estimates, and Combat Stress/Human Factors. We then grouped all studies that fell within these categories and selected one specific study topic from each group. Our next step was to conduct research in the central data repositories. Our purpose was to determine how many studies were completed during the past 10-year period that were either directly related or closely related to the chosen topic. The following provides the results of this research.

TOPICAL AREA	STUDY TOPIC	# OF STUDIES DIRECTLY RELATED	# OF STUDIES CLOSELY RELATED
Ammunition	Ammunition Rqmts/ Rates	43	57
Transportation/ Mobility	Rail Mobilization Outload Requirements	42	66
Casualty Estimates	Casualty Estimation Analysis	21	21
Combat Stress	Combat Stress/ Human Factors	79	18

This research told us that there is a tremendous potential for duplication of effort in the studies arena. It clearly illustrates the need to mandate pre literature searches prior to study approval and funding. This in turn will help the analytical community capitalize on previous work and reduce duplication of effort. AMIC in its final report will recommend mandatory pre literature searches prior to any study approval and funding under the AR 5-5 program.

3. Prioritize study proposals in coordination with DCSOPS. After AMIC had obtained all FY 90 study proposals from the SPMA, a series of working sessions were conducted in coordination with DCSOPS. The intent of this initiative was to examine all MACOM and ARSTAFF functional mobilization study proposals from an overall perspective and prioritize the most critical ones. This prioritized list was provided to the SPCC for their use in approving and funding mobilization studies. Since DCSOPS has overall responsibility for Army mobilization planning, they were the obvious organization to provide an overall perspective. Determination of a study's criticality was based on stated Army leadership concerns regarding mobilization capabilities. These concerns were identified through the General Officer Mobilization Review (GOMR) Committee proceedings, Army Remedial Action Program, IG Reports, and the DCSOPS working knowledge of the most pressing issues.

4. Identify additional mobilization study proposals for funding under the Army Study Program. AMIC has been in the unique position to observe mobilization planning from both a functional and an overall perspective. This has enabled us to identify disconnects between what the Army leadership feels are the critical issues and what the Army analytical community is actually working on. Based upon these observations for the past two years, we feel there is no consolidated document/reference that describes obstacles facing the Army for each stage (partial, full, total) of mobilization. Current mobilization planning focuses predominately on the current and program forces. Planning for increasing the force size under a full or total mobilization is minimal. The limited planning that is accomplished is not integrated with current and program force planning. This precludes senior Army leadership, such as the GOMR Committee, from viewing the full range of obstacles and requirements facing the Army at different stages of mobilization. Without this overall perspective, decision makers cannot provide proper direction and prioritization to resolving issues that provide the most benefit to all stages of mobilization.

To improve this situation, AMIC proposed a study/analysis for the FY 90 Study Program. This initiative will develop an analytical road map which provides a progressive and logical determination of major obstacles facing the Army at each different stage of mobilization (partial, full, total). This analysis will identify and consolidate these obstacles in a logical manner into one document. Further, it will develop the essential elements of analysis for resolving each obstacle. Conduct of this study will require full participation from ARSTAFF and MACOM leaders. It will be incumbent upon them to have their organizations identify impediments to accomplishing the six major mobilization requirements--equipping, manning, training, deploying, and sustaining the force at each level of mobilization. The resulting product should provide senior leadership (GOMR, ODCSOP, OTHER ARSTAFF, MACOMs) with a consolidated list of obstacles/issues at all mobilization levels. This will better enable prioritization and direction by the Army leadership for required decisions, actions and analytical efforts for resolving mobilization obstacles. In essence, it enables both leaders and planners to work off the "same sheet of music."

FUTURE AMIC ACTIVITIES

There is a tremendous amount of activity taking place within the mobilization planning community. AMIC will focus its future activities on improving the orchestration of these activities. We will make every effort to ensure that the Army leadership has the adequate information to develop a mobilization master plan. From this plan, they can make decisions and direct and prioritize mobilization planning efforts. We will continue our efforts to ensure that mobilization planners are maximizing the use of existing analytic tools and resources. Finally, we will continue our efforts to improve coordination within the mobilization planning community and between them and the study community.

SYSTEMATIC ORGANIZATIONAL DESIGN (SORD) METHODOLOGY DEMONSTRATION

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ABSTRACT

The Systematic Organizational Design (SORD) methodology is a user-oriented, computer-assisted tool that creates a standardized process and structure in which an Army organizational unit can be designed. The background and status of the SORD development are described, an overview of the SORD methodology is presented, and each major component of the methodology is illustrated using examples taken from a field test of SORD. Finally, the benefits that can be derived from the recent institutionalization of SORD and its future refinements are discussed.

INTRODUCTION

Genesis and Stature

The US Army Research Institute (ARI) unit design project began under GN Thurman when he was the Department of Army Deputy Chief of Staff for Personnel (DCSPER), and received continuing support under his successor, LGN Elton. Both DCSPERs encouraged ARI to address the Army's need for standardized and objective methods for organizing soldiers and their equipment into cost and operationally effective units. The SORD methodology was designated one of the highest priority ARI research tasks by the US Army Training and Doctrine Command (TRADOC) during the final two years of its development. SORD will soon become the required, standard technique for designing Army units, as specified in the draft TRADOC Regulation 71-17.

The Force Design Context and Process

Our initial review of Army and TRADOC regulations that address the force design process and interviews with force designers at selected TRADOC facilities showed that it is a major factor in the Concept Based Requirements System (CBRS), and is so beginning at the earliest stages of the CBRS. The processes and activities TRADOC employs to determine "How the Army will fight," requires the early formulation of ideas, evolving into more detailed concepts, on how to organize units to conduct and support that fight. These initial concepts for organizing units are incorporated into a supporting document called the Unit Reference Sheet (URS). The URS supports and is a basis for later conceptual and doctrinal studies and analyses, and depicts, in summary form, the Table of Organization and Equipment (TOE) unit expected to result from approval of the study or concept.

Once the organizational concepts contained in the URS are approved, there are numerous prescribed and often automated planning documents that will refine the URS and give shape, size, and detail to the organization created. For example, all of the following documentation build on the URS: the Automated Unit Reference Sheet (AURS), the Basis of Issue Plan (BOIP), the Qualitative and Quantitative Personnel Requirements Information (QQPRI), and the results of Manpower Requirements Criteria (MARC) studies contained in AR 570-2.

Yet, by the very nature of processes that govern the development of concepts, the URS development process must be a creative act oriented toward the future, and relatively unconstrained by regulations and doctrine that prescribe how to organize and use "available" resources. The URS development process must portray an objectively derived design for "future" battles that may employ resources and doctrine that do not now exist.

The process that currently exists to develop a URS is designed to facilitate a search for innovative solutions to unit design issues. After HQ TRADOC initiates a major force structure study, the Current Force Design and Modernization Directorate (CFD) at the Combined Arms Combat Development Activity (CACDA), Fort Leavenworth, acts as the study agency. The CFD-CACDA convenes a series of action officer workshops for the combat developers responsible for the functional areas incorporated in the mission of the unit to be designed or redesigned. With guidance provided by the CFD-CACDA, subject matter experts from the responsible TRADOC schools/centers will repeatedly revise and finally integrate their respective portions of the unit into one URS. Then, the URS undergoes a lengthy review and revision process until it gets approval by the Chief of Staff of the Army.

While "The Process" works, it is hindered by the absence of an explicit methodology, i.e, tools or aids that could facilitate the process. Consequently, it is much less efficient that it could be. Incorporated in the process are the experiences and traditions of the combat developers who comprise the process. In other words, the process by which these designs are conceived is peculiar to each combat developer. As a result, repetitive communications among decision nodes are required before various portions of the design can be integrated into one URS. The process is similarly hindered as the URS moves through the review and approval chain. This lack of efficiency in the URS development process is further confounded by the fact that the time available for the process is generally quite limited. Furthermore, there is no procedure or requirement for maintaining an audit trail. Consequently, independently convened URS development teams could each create perfectly valid designs that differ in substantial ways from each other, without anyone being able to determine what differences there may have been in the design rationale that caused the designs to be different.

Army Need

The need therefore exists, not to change the process in any fundamental way, but to standardize the process and make it work more effectively, efficiently, and reliably.

(1) A standardized process will drive and control the development of a URS. Once the process is in the hands of the study agency at the CACDA integrating center, the study manager will be in a position to be proactive rather than reactive in the guidance given to the team members.

(2) The rapid pace of changes in mission requirements, high technology,

and equipment and personnel assets has produced a high workload for force designers; over the past several years TRADOC has had to design or redesign over 300 TOE units per year and for each unit up to three URSs have been created. There is good reason to believe that the numbers of unit design programs will grow rather than shrink, and that the number of authorized designers will shrink rather than grow.

(3) There is a movement to centralize the TOE documentation process. Now, the same combat developers who create the URS subsequently document the TOE. If the latter process is centralized it will be critically important that the URS be completed in a manner that permits the combat developer to control the framing out of the unit -- to insert their design intelligence.

Solution

Our approach to addressing this need was to develop a user-oriented, computer-assisted methodology that would address three basic components of the current URS development process. These components became subsystems of the overall methodology. They address, respectively:

(1) The need to insure that the unit design process is driven by the unit's mission;

(2) The actual designing of the structured unit, with its required assets; and,

(3) The need to verify that the designed unit does have the capabilities required.

Procedures

We have been fortunate in acquiring the guidance and direction of an excellent proponent. Working with and through the force design community at the CACDA, we have interfaced with force designers at all the TRADOC schools and integrating centers, and have benefited from their reactions to our developing methodology. Finally, we were able to maintain a close and mutually productive relationship with the organization directorate at HQ TRADOC to insure a fit between the SORD methodology and those processes that build on a URS to documentation a TOE unit.

We followed the usual and highly regarded path for developing a useful computer-based methodology. After developing a macro-model of the URS development process, we developed and verified design specifications, created and demonstrated rapid prototypes of computer screens, and, as the various utility and other functions were coded, demonstrated, verified, and refined successive prototypes of the methodology on the basis of feedback received from the proponent and user community. A pilot test of the complete methodology was conducted at Ft. Leavenworth under the direction and close scrutiny of the force design directorate.

After making refinements to the software and user's manual based on the results obtained during the pilot test, the SORD methodology was field tested in January of this year. There were six players in the field test whose experience with personal computers and with the unit design and documentation processes ranged from zero to over 10 years. Each player designed two units. Collectively, a total of six different types of units were designed ranging in complexity from a headquarters and headquarters company of an armored brigade through an air defense artillery weapon firing battery to a personnel service company. During the field test, each TRADOC designer used SORD to design a unit from scratch. After some final fine-tuning based on results from the field test, the SORD methodology, along with full documentation of its source code and a user-verified user's manual, was handed over the CFD-CACDA in February 1989.

Since then, TRADOC has funded development of SORD Version 1.5, which will soon be fielded across all TRADOC facilities. Presently, TRADOC is sponsoring some additional fine-grained refinements to SORD that will also address changes in the methodology driven by feedback from the user community.

THE SORD PROCESS

Objectives

The point that must be stressed here and elsewhere is that while SORD will create a standard structure in which a combat developer will design an Army unit, SORD cannot be used as a substitute for the thought processes of an experienced unit designer or, at least, an experienced combat developer. The following conditions both drove and constrained the development of the SORD methodology.

(1) The user of SORD is an 03/04 commissioned officer or a civilian with comparable military knowledge and experience. SORD further assumes that the user has access to and is aware of sources of information that are required to develop a URS. In short, SORD assumes an expert user.

(2) SORD assists the expert user in moving in small steps, one standard and manageable step at a time, from the receipt of a unit's missions through to the printout of a completed URS report. During the process, SORD gives appropriate structured guidance through the use of probe questions, keywords, examples, and other prompts. Where appropriate and possible, SORD will make available information from internal databases. Throughout the process, SORD provides a pre-formatted working file in which the user will record his or her inputs to the development of the URS. When the URS is completed, the user will also have recorded a complete audit trail so that others will be able to reconstruct each step that was taken during the development process.

(3) SORD is flexible. The user may skip steps in the process and come back to them after finishing other steps. At some stages in the process, the user is permitted to add his or her own steps. In short, SORD is not a locked-step serial process. SORD is also flexible in that it is transportable; different parts of the SORD process may be performed, sequentially or simultaneously, by several geographically dispersed individuals.

(4) SORD is fast. A guiding rule in the development of the SORD methodology was that it is better to have an 80 percent solution in hours that a 95 percent solution in weeks or even days. The speed at which SORD will

permit the development of a URS is, of course, a function of the extent to which the user has relevant experience and that the user has incorporated information unique to his or her mission area into the internal SORD databases.

The Process

The flow diagram in Figure 1 shows the major components of SORD. Here, we can see the three major components of SORD, the Mission to Function Subsystem (MFS), the Unit Design Subsystem (UDS), and the Design Evaluation Subsystem (DES). As can be seen in Figure 1, SORD also incorporates a Crew/Cell Database, and a report producing module. Each of these components of the SORD methodology will be described in succeeding sections.

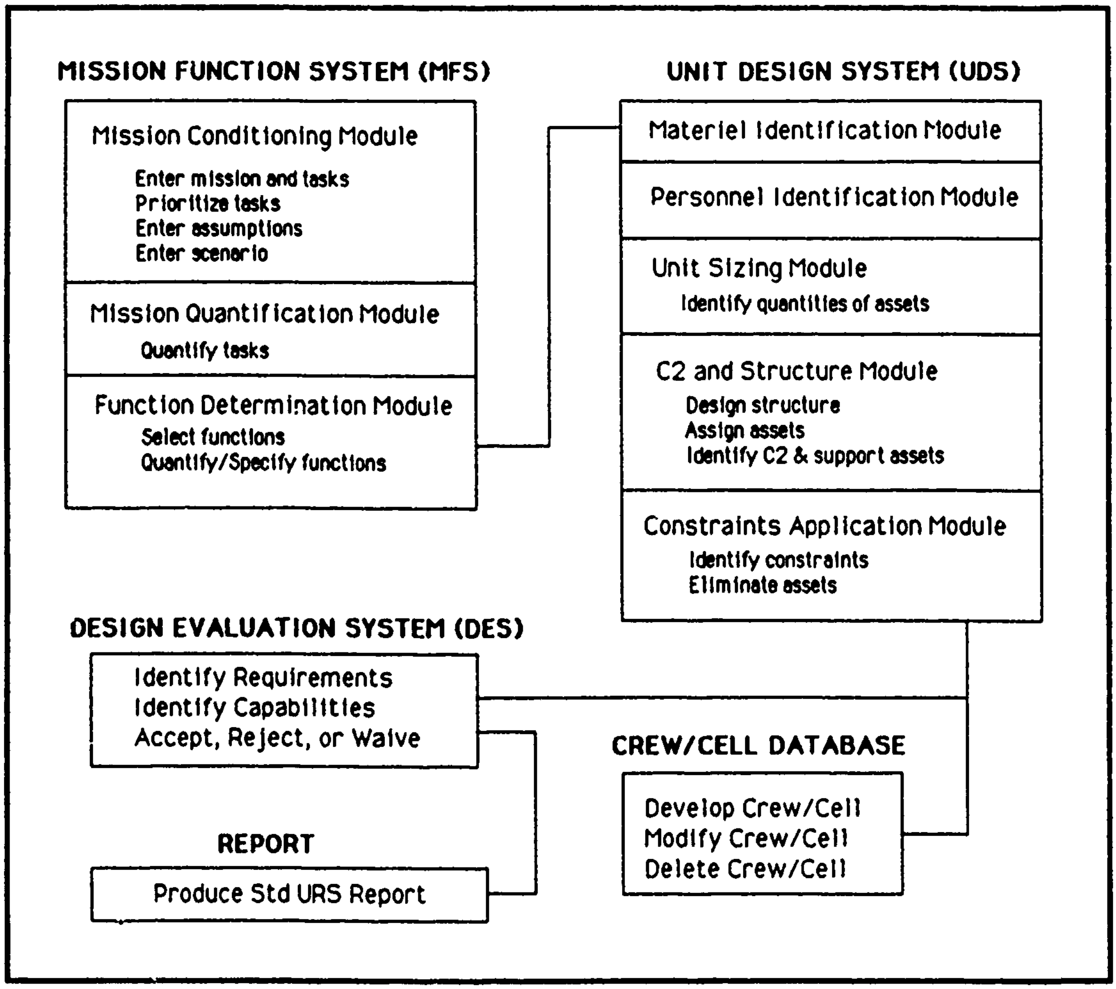

Figure 1. A flow diagram showing the components of the SORD methodology and the users' possible transition among these components.

Mission to Function Subsystem (MFS)

The mission to function subsystem is designed to ensure that the unit's design is driven by its mission. This requirement of a designed unit is currently one of the weaker steps in the URS development process. Presently, mission analysis is often derived in an unstructured, subjective manner from information contained in concept papers and doctrinal literature. Furthermore, the results of a mission analysis are rarely as quantitative as they should be. This step in the design of units (in which mission requirements should be designated and translated into quantified statements of required functions and subfunctions) is probably the largest source of variation in URSs produced by different combat developers. The MFS contains three modules.

The first module in this subsystem, call "mission conditioning", is designed to insure that the mission to be accomplished contains all its required components or objectives, and that the user fully understands the unit mission and its related context. The system prompts the user into gathering information necessary to create an organized database, worksheet, or schematic that will be used to define the unit's required capabilities. Specifically, the system offers suggestions on the types of information that is important and where it might be found, to include the concept of operations, area of operations, and threat specifications, much of which may be incorporated into and/or driven by a standard scenario. A record is created to document the precise source of this information, to include personal, unpublished sources (e.g., a local "expert"). When the user has completed all the steps required by this module, he or she will have clear statements of the mission, the conditions in which it will be accomplished, assumptions made, and prioritized objectives.

The second module, called "mission quantification", prompts the user to provide short answers to a series of questions keyed to each objective of the mission. The user will have to "look up", calculate, or otherwise formulate the answers to these questions, but in the process he or she will quantify or specify the key attributes of the mission. The questions address unit capabilities that are required if the unit is to accomplish its mission; questions such as: "How much, how far, how fast, how long, and how accurately". The user may ask, then answer a question not given by the system if he or she believes it will further quantify an important attribute of the mission.

In this and other components of SORD, the user may freely move between modules and steps within a module until required data, i.e., inputs, are available. The user may also default a question or probe; some broad attributes may defy quantification or specification and/or simply not be applicable for a given mission or objective. When the user has completed all the steps required by this module, he or she will have a collated list of the composite requirements for each objective of the mission.

The third and last module in MFS, called "Function Determination" assists the user in decomposing each mission objective into the functions and subfunctions required for accomplishment of the mission. For the purposes of the URS, it is sufficient to decompose each objective into up to seven action verbs and some direct objects of the verbs, for a total of 19 functions. These generic functions are all inclusive and capable of capturing the actions required of any type of unit. Then, by working through a different but similarly structured and menu-driven worksheet for each of the applicable functions, the user will further specify and describe the functions that must be accomplished if the mission is to be successfully accomplished. For example, if a function of the unit is "to move cargo", the user could specify such function attributes as what types of cargo (bulk, fuel, or water), how it is to be transported (foot, ground, air, or water), and over what distance (less than 3 km, 4 - 10 km, or more than 10 km).

After the user has iteratively interacted with SORD through the three modules contained in the MFS, he or she will have documented the results of a mission analysis that specifies, down to the function level, the precise requirements that must be fulfilled by the unit if it is to accomplish its assigned mission. Given this information, and the experiences acquired in the process of documenting it, the user is ready to actually design the unit.

Unit Design Subsystem

The unit design subsystem will aid the user in designing a structured unit comprised of the appropriate numbers and types of major materiel and personnel asset, those that have the capabilities required to accomplish the mission. Basically this is done by matching functional requirements of the mission with the capabilities of key materiel and personnel, and then sizing out the unit and organizing it into a structured entity. The UDS consists of five modules.

The first two modules of the UDS, called, respectively "Materiel Identification" and "Personnel Identification", operate in a similar manner to assist the user in identifying candidate materiel systems and soldier specialties to be used in the unit to perform the functions previously specified. Currently, the user must have access to and manually input to SORD information from materiel and personnel databases that describe the capabilities of potential assets. For example, that each member of a particular class of tanker trucks can each transport 2500 gallons of fuel and that a trailer mounted tank can hold 600 gallons. Or, that two military occupational specialties (MOS 76Y and 77F) have the capability to satisfy a mission requirement for receiving, storing and processing fuel.

A comment is required in regard to the SORD databases. Two requirements for the materiel systems database were agreed to by representatives of ARI, CFD-CACDA, and the Organization Directorate at HQ TRADOC. The materiel system data must be capable of cross-reference with the TOE database and must therefore be linked to a line item number (LIN). Furthermore, since each user of SORD may have local concern for and knowledge of unique technical characteristics of a materiel item, there must be provision for user input to the database. Three existing databases that meet the first requirement are maintained by the directorate of information management (DOIM) at Ft. Leavenworth. Once edited and integrated (i.e., merged), these three databases could serve as the basis for a standard materiel system database for SORD. Users (i.e., local designers) could augment the standard database but not otherwise change it. The personnel database used in this module could be derived from the DA 611 series database currently being developed by HQ TRADOC. This personnel database is being designed to feed the TOE documentation process.

(i.e., the TOE builder/calculus), and is scheduled to be partitionable into manning cells. These features of that database will enhance its use in the SORD methodology. On a periodic basis, the proponent would update the three materiel systems and the personnel databases, and remerge them with the augmented input from the user community. The updated databases would be redistributed to the user community for incorporation into their local SORD system.

Once candidate materiel systems and personnel have been identified, their relative capabilities must be matched against the mission requirements they have been identified as satisfying. In the Unit Sizing Module, SORD will assist the user in this task so that he or she can tentatively assign the necessary numbers and types of candidate materiel systems and personnel to the unit. SORD reminds the user of any unassigned candidates and makes available to the user any of the information previously inputed into the working file. For example, the user may designate that a specific number of 2500 gallon tanker trucks are required to move a required volume of fuel under conditions specified in the mission scenario; SORD would remind the user that 600 gallon fuel tanks carried on trailers also had been identified as satisfying the requirement to transport fuel.

The Command and Control and Structure Development Module assist the user in creating an organizational structure for the unit and in assigning additional personnel and materiel to satisfy requirements imposed by command, control and support functions. The "Structure Submodule" prompts the user to review relevant doctrine, concepts of operations and other documentation in order to identify any guidance that may suggest how personnel and materiel assets could be organized. For example, organization guidance generally recommends symmetry in structuring a unit; like elements have the same number and types of assets. Then, working from the lowest level organizational element, the user names the element and assigns assets to it. Once all the different types of lowest order elements have been defined, the user is guided into naming the next high-order element and assigning to it lower level elements. The process is repeated until all assets have been assigned. SORD will keep tract of and display assets not yet assigned.

The "C2 Submodule" starts with the assignment of C2 personnel to the lowest level elements of the unit and moves up through higher level elements. SORD present to the user the grade structures recommended for each element (based on guidance in the AR 611 series). For example, a typical infantry platoon is authorized an E7 platoon sergeant and an infantry company, an E8 fist sergeant. Finally, the user will be encouraged to determine if any of the C2 or support assets added to the unit call for the assignment of additional assets (e.g., a vehicle for the first sergeant).

The last module in the unit design subsystem, called "Constraints Application", permits the user to determine if the unit, as tentatively designed, has exceeded any materiel or personnel constraints that had been imposed. If so, the user is directed to AR 310-31 for guidance in TOE reduction. SORD also will display objectives that were previously rated as having the lowest priority for the unit. After reviewing these materials, the user will select specific assets to be eliminated from the unit design. At this point, a unit has been designed that possesses the assets required to accomplish its assigned mission.

Design Evaluation Subsystem (DES)

The last major component of SORD, the design evaluation subsystem, will aid the user in assessing and verifying that the capabilities of the unit designed in the UDS will match the mission requirements that were determined in the MFS. The DES also will maintain a file of all unit designs (including alternative designs for a specific set of mission requirement) and provide a format for report generation.

Two key terms to note here are verify (as opposed to validate) and capability (as opposed to effectiveness). At this stage in the CBRS it is necessary only to confirm that the mission requirements derived in top-down MFS process, are matched by the capabilities of the designed unit, that were derived in bottom-up UDS process. Also, at this stage in the CBRS it is necessary only to address the aggregated capabilities of the materiel and personnel assets that were organized into the designed unit. It would be premature at this point, and would require much more time and resources than would be available, to attempt to validate the actual operational effectiveness of the designed unit. These ultimately necessary steps are more properly assigned to wargaming exercises.

SORD will assist the user in comparing the characteristics and capabilities of the designed unit, structuring those capabilities into a format similar to that used for defining mission requirements, with the mission requirements. The unit's capabilities and the mission requirements are presented side-by-side on the computer screen, separately for each function within each mission objective.

After examining the capabilities and requirements, the user must indicate that he or she accepts or rejects the designed capabilities of the unit. As an intermediate action, the user may waive or postpone making a definitive decision, but flag that particular designed feature of the unit for additional scrutiny by indicating that there is either an over or undercapacity designed into the unit for a particular function. Some mismatches between requirements and capabilities may lead the user to consider redesigning the unit, or reassigning a function to a higher, supporting, or supported element. The rationale necessary to support or clarify any decision can be recorded in a memo field for later reference.

Once the user has completed reviewing and acting on all the comparisons of capacities and requirements, he or she can store the entire working file for that design exercise into a history file for later reference, or instruct SORD to prepare and print a report based on information contained in the history file. All the information inputed and used in developing the unit design, including sources of data and rationale for decisions are available in the file for later examination.

Crew/Cell Database

The crew/cell database is a component of SORD that can be used to develop crews or cells of personnel and materiel assets. The idea behind this database is that there will be specific clusters of assets that will be used repeatedly in designing different elements within a unit and also across different units.

The crew/cell database will permit the user to develop such a cluster of assets and then store that information. Once stored in the database, the assets that define a crew or cell can be called up and used at several points in the UDS.

SORD treats a crew and a cell differently. A crew is defined by SORD to be a group of personnel that are employed in conjunction with a particular materiel system (e.g., a M109 155-mm self-propelled howitzer); if that system is assigned to a unit while the user is in the UDS, SORD can automatically call up and include the crew of the system into the personnel assets file for the unit. On the other hand, SORD defines a cell as a cluster of personnel that perform a function within a unit but are not linked to a particular materiel system (e.g., an S1 section of a headquarters and headquarters company). When operating within the UDS of SORD, the system will prompt the user to include as appropriate any cells that had previously been developed and store in the database.

Report Generator

At present, SORD has the capability to generate a single, standard formatted URS report only. This feature of SORD can, of course, be upgraded to permit the production of a variety of customized reports. Exercising this option in the main DES menu will call up a computer screen that prompts the user to provide information for the report title page, such as the title, proponent, author, editor/reviewer, and date of creation. Once this information is provided, SORD will complete and generate the entire URS report. The report can be produced either on the screen or on paper.

CONCLUSIONS

Summary

The SORD methodology is a user-oriented, computer-assisted tool that addresses three basic components of the unit design process: (a) insuring that the unit design process is driven by the unit's mission; (b) designing a structured unit, with all its required materiel and personnel assets; and (c) verifying that the designed unit does have the capabilities required to accomplish its mission.

To reiterate, SORD will assist the experienced unit designer in preparing, in a standardized process, a unit reference sheet. Equally important, it must be emphasized what SORD does not do. SORD does not replace the experienced unit designer; it is NOT an expert system that employs artificial intelligence. SORD does NOT alter the unit design process; it merely makes that process more efficient and reliable.

Benefits

(1) SORD will permit the rapid development of alternative conceptual designs and the efficient transfer of those designs to others in the combat development process and to those who are responsible for the prescribed and increasingly automated process of preparing organizational documentation.

(2) Because of the thoroughness of the designs it helps to create, SORD will, in most instances, eliminate the need to develop an Automated Unit Reference Sheet in the process of developing draft TOEs.

(3) SORD will permit the centralization of TOE documentation within the Army. Such a realignment will result in substantial personnel and monetary savings.

(4) SORD will serve as a principal component of a war room being created at the CACDA to analyze force design alternatives for future force structure reviews.

Netherlands Army Long Range Anti Armour Study
Status report

Contribution to the Twenty-Eighth US Army
Operations Research Symposium, 11-12 October 1989

by

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Abstract

At the end of the nineties the munition for the TOW weapon system in use at the Netherlands army, has to be replaced. The Life Of Type of the TOW carrier ends in 2005. The long range anti armour study is to gain insight into the possibilities and limitations for the Netherlands army to deploy future (time period 1995-2000) weapon systems in the long range anti armour battle. The first study results are expected at the end of 1989. The study is sponsored by the Netherlands army and is carried out by the three National Defense Research Organization Laboratories: the Physics and Electronics Laboratory TNO, the Prins Maurits Laboratory TNO and the Institute for Perception TNO.

The study considers two categories of candidate weapon systems namely line of sight and non line of sight weapon systems. The Operations Research effort within this study is mainly focussed on analyzing and comparing the effectiveness of the different weapon system options. Therefore wargaming, terrain analysis and combat simulation techniques are used.

In the paper these techniques will be presented and some results will be shown.

1 Introduction

1.1 Study definition

In the nineties the long range Anti Tank Guided Weapon (ATGW) system TOW, currently in use by the Royal Netherlands Army (RNLA), will have to be replaced. Due to the technological developments the TOW system will not necessarily have to be replaced by a same type of weapon system in the same quantities.

For this reason an operations research study has been defined to gain insight in the possibilities and limitations on future alternatives for the (long range) anti armour combat. The study is focussed on the 1995-2000 time period. The study is performed by the three Netherlands National Defense Research Organization Laboratories: the Physics and Electronics Laboratory TNO (FEL-TNO), the Prins Maurits Laboratory TNO (PML-TNO) and the Institute for perception TNO (IZF-TNO).

1.2 Study set up

The anti armour study is divided into three phases. In the first phase an inventarisation of the possible alternatives for the TOW replacement has been made. Helicopters and 'static' anti armour means as minefields deliberately were not taken into account as an alternative for the TOW replacement.

In the second phase the combat simulation model 'Force Structure Model FSM' of the Physics and Electronics Laboratory TNO will be adjusted to the specific study goals. Also technical and tactical simulations at the weapon system level will be performed in order to get a first feeling of the effectiveness of the different weapon systems. Finally, a special substudy to the operator behaviour for Fiber Optic Guided Missiles is performed on the simulator table of the institute for perception.

In the third and final phase a break-even point for several mixes on battalion level and higher will be searched for in one or more pre-defined combat scenarios.

Since during the past decade a lot of studies within the same scope have been performed by the different nations, I will focus this paper on those aspects in the study that were mostly new and have not extensively been studied before.

The current state of the project is that phase 2 is almost completed and phase 3 has just been started. Therefore only results from and techniques used in the second phase will be presented.

It is important to mention at this point that during the definition phase of this project, another project was set up to gain technological knowledge of the Fiber Optic Guided Missile (FOGM) system. This 'National Technology Project Fiber Optic Guided Missiles (NTP-FOGM)' has to prepare both the participating Netherlands Industries and the Netherlands Laboratories to be able to participate in future international developments on this type of weapon system. Since the FOGM is one of the alternatives to be considered in the anti armour study, this study profits from the results of the NTP-FOGM. Therefore I will also mention a few aspects of the NTP-FOGM study that bear direct relevance to the anti armour study.

2 Phase 1: Possible Anti Armour Systems

Performing a study with such a broad scope as defined above, one knows beforehand that the study cannot address all the different weapon systems that could contribute for the solution of the problem. Instead some categories of weapon systems, in relation to the problem, that have some specific characteristics, will have to be defined. Having done that one or two (generic) representatives of that category are taken in order to study that particular category.

2.1 Categories of anti armour combat

During the definition phase of the study two main categories of anti armour combat have been identified: anti armour combat within the Line-Of-Sight and anti armour combat beyond the Line-Of-Sight. The second category has initially been subdivided into a category non line of sight systems with a restricted range (<10 km) and a category of systems with a range beyond 10 km.
First a few remarks on the categories defined.

- the category of Line-Of-Sight weapon systems
  Since the Line Of Sight systems need a Line Of Sight with their target they principally can also be seen by the target, which makes LOS systems principally vulnerable for direct and indirect fire of enemy weapon systems. An advantage of these type of systems is that targets are relatively easy to identify since they can be seen. For the LOS weapon systems the position from which detection takes place and the ammunition is fired is very important. A special group of weapon systems within this category are the elevated platforms. These platforms make it possible to position the system at other (more) locations then with non elevated platforms, (more or less) having the same line of sight.
  Although combat helicopters belong to this category, they are not taken into account in this study.
  The ammunition used can be either a chemical energy munitions, guided (new TOW) or fire and forget (HELLFIRE or TRIGAT), or it can be kinetic energy munitions such as the Hyper Velocity Missile or all other kinds of ballistic projectiles.

- the category of Non Line-Of-Sight (NLOS) weapon systems
  The non line of sight systems can be positioned (depending on the range of the ammunition) almost anywhere in the terrain. This feature makes them only vulnerable for indirect fire. On the other hand it is harder to identify targets for the ammunition. To get an acceptable hit/kill probability for the NLOS category of weapon systems one has to either shoot a lot of ammunition in a certain area (area fire), or to perform a way of guidance of the ammunition, which makes the system more expensive.
  Weapon systems belonging to the guided NLOS category with a limited (<10 km) range are the Fiber Optic Guided Missile FOGM and the chemical energy, terminal guided Mortar Anti Tank MORAT system.
  Weapon systems of the NLOS category with a long range (>10 km) are the Autonomous Precision Guided Munitions APGM for the artillery systems and the conventional artillery such as the MLRS (unguided).

3 Phase 2: Getting acquainted with the weapon systems

The goal of the second phase of the study is to get acquainted with the weapon systems taken into account during the study. For this purpose both technical and tactical data of these weapon systems have to be gathered.

In the Netherlands a national database of weapon system data is available. In this database technical information on both national, NATO and potential adversary vehicles is stored. The data for the database have been gathered over the years by the PML-TNO and are based both upon real life firing tests and on vulnerability models. The technical data of the weapon systems taken into account during the study, and not currently represented in the database, have been gathered in this phase.

Beside the technical information also tactical information about the ways of deployment and usage of the weapon systems is required. These tactical data are for a great part stored in a knowledge based system that drives the combat simulation model 'Force Structure Model' of the FEL-TNO. The tactical rules and doctrines are dictated by army representatives.

However, no tactical rules or ways of deployment for systems like the elevated platform and the fiber optic guided missile FOGM existed thus far in the RNLA. So, in the anti armour study a 'deployment' philosophy for the elevated platforms was defined. Within the National Technology Project FOGM a substudy was performed in defining possible targets for the FOGM. The next part of the paper will focus on these two substudies.

3.1 Elevated platforms

3.1.1 Positioning the elevated platform

In order to determine the possible locations of elevated platforms a terrain analysis in the corps area of the 1st Netherlands corps (1(NL)LK) has been performed. The line of sight conditions for observer heights of 2 and 12 meter have been determined with the aid of a digitization of the Northern German Plane. We divided the corps area into three subareas. In the first area the LOS conditions were relatively bad (<1000 meter), in the second area the LOS conditions were average (1000-1500 meter) and in the third area the LOS conditions were good (>1500 meter). It showed that in the area with good line of sight conditions the elevation of the sight from 2 to 12 meter height improved the situation even further to an average line of sight of over 2500 meter. In the area with bad LOS conditions elevation hardly made any difference.
The calculations described above were made based upon viewpoints that were chosen for ground-based observers. In order to get a feeling on the number of extra positions possible when elevating the eye, we calculated the number of positions from which a target could be seen for an observer height of both 2 and 12 meter. These calculations made it clear that an increase of 50-100% on average (relative to the number of positions for a viewer height of 2 meter) is achieved by elevating the viewer height to 12 meter.

In order to get a feeling on the validity of the computer calculations a terrain reconnaissance in the corps area was made. With a helicopter the lines of sight in a lot of positions, previously being calculated by the computer model, were checked. It showed that, due to the digitisation of

the terrain in 100 meter square grids, the LOS calculations were somewhat optimistic, but on average the resemblance was good.
As a result of the 'real' terrain analysis we now also have digitised the tree lanes and other screen elements in the terrain that influence directly the line of sight, thus getting an even more accurate computer calculation.

3.1.2 Tactical deployment of elevated platforms

To gain insight into the tactical use of elevated platforms a two days wargame session was conducted at the Physics and Electronics laboratory TNO.

In general it can be said that such a session can be seen as a controlled experiment to force doctrine development and raise discussions on crucial parameters and performance estimates. The aim of the wargame thereby is to generate a set of (time evolving) situations in which one or more decisions ought to be taken by the participating army officers. During the decision making process discussions among the participants will take place. Since military people from different parts of the military organization (cavalry, infantry, artillery, engineers, army staff and intelligence) take part in such a session, these discussions will take into account the problems related to the cooperation and communication between these different parts. The monitoring of such a session (i.e. leading and steering the discussions) is the responsibility of the operations research group involved.

From earlier studies (Helicopter study and Scatterable Mines) it had already become clear that such a session could contribute significantly in the formation of a military doctrine in using new kinds of weapon systems.

For this session the Netherlands wargame KIBOWI was used. KIBOWI is a fully interactive, user-friendly, real time wargame that is excellently suitable for such a session. Both own and enemy forces are played by military people.

During the two days a total of six different team (company) scenarios were played in two different terrain areas, one with bad line of sight conditions and one with average line of sight conditions. In three of the six simulations each blue team had one platoon with four elevated platforms each at their disposal. Mounted on the elevated platform were 12 TOW-like missiles with a maximum range of 5 km.

From the session it became clear (as we already knew after the terrain analysis) that more locations were available to the elevated platforms in order to gain control over the enemy route. Due to the increase of possible locations the long range of the system could often be used, whereas the non elevated, long range, weapon systems could not fully exploit their range.

The elevated platforms were deployed by the military either on a 'stand alone' basis or in groups of two systems.

In the terrain with average line of sight conditions it became clear that some relation must be made between the obstacle plan and the (effective and useful) long range of the elevated platform. One of the questions raised was whether we also have to put our minefields further away because of the range of the elevated platform, risking a higher chance that the enemy circumvents the minefield or that we lay our minefields as close to the defensive line as we used to do, risking that the enemy will not reach it, or that we should search for positions for the elevated platforms further in the depth of the blue team.

Finally the session showed that by elevating the sight tactical important terrain areas as river crossings, which mostly lie in the deeper parts of the terrain, can be kept both under surveillance and under direct fire from great distances whereas this could not be done by non elevated sights.

3.2 Fiber Optic Guided Missiles

3.2.1 Defining FOGM targets in a brain storm session

The problem that had to be addressed for the NTP-FOGM study (and also for the anti armour study) was to define the operational environment for a Fiber Optic Guided Missile.
Since the FOGM has a number of important aspects that makes it different from other weapon systems, the (possible) use of such systems in a battle field is not at all trivial.

In order to define specific FOGM scenarios a two days brain storming session was organised. In total 25 people participated in this session: 8 army officers, 7 people from industry and 10 people from the defense laboratories.

3.2.1.1 Organization of the session

Twenty-one people were divided into four task groups, the remaining four people formed the special FEL-study team that controlled the session and took care of on-line documentation. In each task group were representatives from the army, industry and the laboratories. During the two days each task group had to study a number of characteristic enemy situations and to identify the possibilities for FOGM to attack the enemy in that situation.

The session was organised in such a way that in a limited time period a large number of different study tasks could be addressed by the task groups.

The session was divided into five main parts. In the first four parts of 2.5 hours each, each task group had to work out a specific FOGM topic (1.5 hours). In the remaining hour the task groups had to present the results from their mini-study and discuss these with the other groups. In the fifth and final part the experiences could be 'tested' in a wargame (KIBOWI) that included FOGM systems.

3.2.1.2 The task of the task groups

As it has been stated before, a task group had to address a specific topic concerning the (possible) use of FOGM. For this they were given a simple description of a characteristic situation of the enemy and, based upon that description, they had to identify the possibilities for FOGM to attack the enemy. The task groups were urged to address at least the next subtopics:

- targets

identify the number, types, formation and (expected) statuses of the enemy structure.

- threat
  analyze both the direct and the indirect threat for the FOGM system related to the enemy behaviour and structure.

- FOGM tasks
  identify how FOGM could be used to decrease the enemy threat.

- information
  identify how the FOGM station gets its information and how accurate and recent the information should be.

- target acquisition
  identify how the targets can be acquired by FOGM based upon the available information. Also identify whether special demands for information accuracy or for the controlling system of FOGM (flying speed, navigational aids, seekers etc.) exist.

- effectiveness needed
  identify how the goal of the FOGM attack could be reached.

- alternatives
  identify the available alternatives to reach the effect as identified for the FOGM. If alternatives exist, identify the advantages and disadvantages of using FOGM.

- mission description
  Based upon the previous items, give a short description of the FOGM mission.

3.2.1.3 Results of the session

The results after two days of hard labour were extreemingly good. All participants had gained a lot of insight into possible FOGM usage. As a result of the session six different FOGM scenarios are defined. The NTP-FOGM study will use the scenarios to define the (hardware) requirements for such a system and the anti armour study will use the doctrine adopted in this session.

3.2.2 Operating a FOGM

One of the important aspects of FOGM is the man in the loop. To get a feeling of the requirements, possibilities and constraints enforced by this feature a study to the operator performance is performed by the Institute for perception TNO (IZF-TNO).

On a large table a scale model of a part of the Netherlands corps area has been built. On this modle enemy vehicles and helicopters can be positioned. Above the scale model a small camera, representing a FOGM, can be manipulated. In a special FOGM operator control unit with video monitors, FOGM control yokes etc., a human operator can 'fly' his FOGM and try to find enemy targets. A model of the flight behaviour of the FOGM is incorporated in the system.

For the anti armour study simulations (with TOW gunners as FOGM operators) have been performed in order to investigate the possibility of FOGM finding its target in relation to:

- the available information on target positions,
- the type of terrain and
- the type of the targets.

Currently the results of these simulations are being analyzed.

4 Phase 3: comparing the different weapon systems

In the third and final phase of the study the different weapon systems that could replace the TOW systems will be compared with each other. This comparison will be done by performing combat simulations with the combat simulation model Force Structure Model FSM available at FEL-TNO.
A set of different options will be defined and simulated. The results of these simulations will be compared with the simulated -results of a predefined reference case.

4.1 Features of the Force Structure Model

The Force Structure Model FSM is a closed, stochastic combat simulation model. In FSM the lowest level of representation of friendly and enemy forces can be either the single vehicle level or the platoon level. In both cases the combat evaluation takes the single weapon systems into account. Principally there is no upper limit at which the FSM can run, but due to practical constraints (required computer power) the highest level that can be simulated is the brigade level. FSM is played on a digitisation of the Netherlands corps area.
The combat units in a simulation are driven by a scenario. The scenario is partly stored in a knowledge based system. The other part of the rules and doctrines are set for the simulation scenario by the study team. In a FSM simulation the complete hierarchical structure is represented, thus being able to take into account command and control features (e.g. the delay times it takes to translate and transfer an order from a battalion commander eventually to all subordinate platoons).

4.2 Choosing the operating area

The choice of the operation area is of great importance within the study. The line of sight weapon systems can exploit their specific characteristics only in a terrain area with line of sight conditions over 2000 meter. Although NLOS weapon systems can also be used in this terrain, they will mainly be used beyond the line of sight (i.e. attacking enemy units in depth or from positions further away from the FEBA).
To study the effects of both categories of weapon systems simultaneously a operating area with LOS conditions ranging from 1000-2500 meters has been chosen.

4.3 Levels to be simulated

The smallest combat unit (of combined arms) that fights independently is the team (company). Therefore the effects of the long range anti armour systems can at best be measured relative to the team combat. The reference case will be the situation as it exists at the moment, simulated in the two types of terrain described above.
However, the effects of the non line of sight weapon systems on the team combat will be indirect and therefore only be measurable in a later phase of combat. Because of this the effect will influence the combat of the (next) higher levels battalion and brigade.
Due to the specific characteristics of the NLOS weapon systems these systems will be incorporated on battalion or brigade level. Thus it is necessary to simulate combat at that level.

4.4 Simulation options

At first only the LOS weapon systems will be evaluated. Next also the NLOS weapon systems with a range less then 10 km will be evaluated. The long range (>10 km) NLOS weapon systems will be taken into account by means of two options:

- no such systems are available and thus the enemy will not suffer any harm from these systems and

- these systems are available and their effects on the enemy will be represented as a parametric variation of the enemy strength.

The first results of the simulations with the line of sight weapon systems are expected at the end of this year.

5 Conclusions and remarks

From the current state of the study it can be concluded that elevated platforms make it possible to attack the enemy at a greater distance, from points in the terrain that cannot be used by non-elevated platforms. Elevated platforms make it possible to overview deep parts of the terrain that cannot be seen by non elevated platforms.

Wargaming and brain storming have proven to be very useful techniques to gain tactical information on the use and deployment of new weapon systems. Sessions based upon these techniques should be well prepared. The tight time schedule enforced on the participants of the brain storm session proved to overcome standard reactions and revealed more inventive thinking.

SOME PROBLEMS IN DETERMINING THE RELATIVE COST EFFECTIVENESS OF LAND AND AIR SYSTEMS IN A LAND-AIR BATTLE

BY

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1.0 INTRODUCTION

One of the questions most frequently asked of the operations research community is the contribution of air power to the land battle. Such questions are particularly vocal when money is short and there is competition for funds.

In this paper I will focus on the NATO Central Region and introduce a measure of effectiveness which takes account of the ability of the attacker to concentrate his forces in chosen sectors. Using this measure I will then present the results of some very simple analysis comparing various ways of augmenting NATO's defense capability. This will be used to highlight some of the key problems in trying to quantify an optimum mix of systems.

2.0 THE SHAPE OF CONVENTIONAL CONFLICTS

2.1 Soviet Doctrine

The elements of Soviet doctrine are surprise and the concentration of forces into weak sectors so as to achieve rapid penetration and envelopment of NATO forces (Figure 1)[1,2]. The current threat involves hordes of WP forces, arranged in echelons.

But the future will be different if the progress being made in arms control talks is translated into real and permanent reductions of forces. This would not of course make a future war impossible, but would certainly imply that there would be fewer forces on the ground. However, with the current Soviet doctrine being so firmly underpinned by historical experience, it is unlikely that the basic elements of their doctrine would be substantially different.

2.2. A Possible Conflict with Current Force Levels

The reference literature[3] gives general agreement on a threat to AFCENT of some 90 divisions, although this is very much a "worst case" situation. NATO forces likely to be available a few days after mobilisation comprise about 27 divisions[4], augmented later by about 5 divisions from the US and by some French units. For the purpose of the present paper it is convenient to assume that all divisions have the same fighting capability.

Let us assume that the WP forces divide themselves into 'echelons' with a first echelon of 30 Divisions whose main tasks are to find weak sectors which can be exploited by the second echelon and then to pin down NATO forces in other sectors so that they cannot be re-deployed into the WP main thrust axes. Assume that NATO forces are divided uniformly into 9 'corps' sectors each with 2 Divisions forward and 1 as a corps reserve (Figure 2).

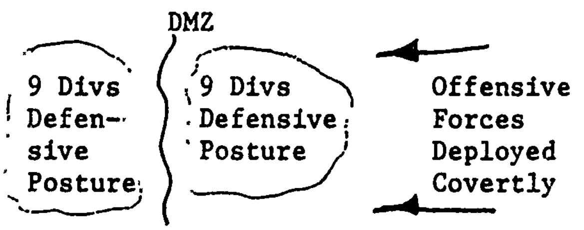
Operational analysis generally shows that forces in well-prepared defensive positions can hold attacking forces some three times their strength. On this basis we might expect NATO's 27 in-place Divisions to hold 81 WP Divisions if these attack uniformly across its front. This is more than adequate to counter the 48 WP Divisions held at a high state of readiness (Cat A Division) and could almost counter the worst case threat of 90 Divisions. The WP would clearly be imprudent to attack in these circumstances. If he does wish to attack and to have a good assurance of success then a strategy of surprise combined with focusing his thrusts into weak sectors is essential. In this way he has a better chance of avoiding attacking forces in prepared defensive positions and of forcing NATO into meeting arrangements where the exchange ratio is more likely to be 1:1 than 3:1. We can illustrate the benefits of such a strategy to the WP with a few numbers, calculated as shown below*.

Figure 3 shows how the minimum number of divisions that the WP would need to deploy to achieve a breakthrough varies with the number of major thrust sectors. The top line is for a case where NATO's forward divisions are in well prepared defences (3:1 exchange ratio), but NATO's reserves are engaged in meeting engagements (1:1 exchange ratio). The next line shows the effect of a surprise attack where the forward NATO Divisions have only been able to set up a limited defensive position. Here an exchange ratio of 1.5 has been assumed (based on Col. Dupuy's historical analysis (reference 5)).

It is seen that the combination of surprise and concentration considerably reduce the number of forces the WP needs to achieve breakthrough.

2.3 Possible Future Conflicts

The future depends very much on the outcome of the current arms control negotiations. With a reduction in the number of WP tanks to about 1/3 of their current level being considered, we might expect the Category A divisions in GSFG, E. Germany and Czechoslovakia to f 11 to perhaps 9. Let us assume that these are deployed as a thin defensive area East of the DMZ, and that NATO deploys in a similar way with no in-theatre reserves.



If now the WP can assemble offensive forces covertly and launch an attack before NATO can bring reserves in, we can produce the lower lines in Figure 3 using the same calculation method as in para 2.2

It is apparent that, as for current force levels, surprise and concentration of force are of great advantage to the WP.

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* For x main thrust sectors, the minimum number of WP Divs. needed to breakthrough is:

$$\frac{30}{9}(9-x) + x(2 * E_D + 1 * E_R)$$

$\frac{30}{9}(9-x)$: Holding Forces; 2: 2 forward Divs; E_D: Exchange ratio of forward Divs; 1: 1 Reserve Div; E_R: Exchange ratio of reserve Divs

3.0 A MEASURE OF FORCE EFFECTIVENESS

If we want to compare the effectiveness of different ways of augmenting NATO's defensive capability, we can use as a measure the additional forces that the WP would need to achieve a breakthrough. Thus using figure 3 as baseline , force enhancements that raise the numbers of divisions needed for attacks in a limited number of sectors and for surprise attacks are clearly going to be preferable in that they are robust to a variety of WP strategies.

4.0 SOME OPTIONS FOR AUGMENTING NATO'S CONVENTIONAL CAPABILITY

To illustrate the main factors involved in any trade-off analysis, only a few of the possible augmentation options have been considered. These are listed in Table 1; divided into two broad categories.

(i) line-of-sight weapons or those with a range of a few tens of kms.

(ii) long range weapons which can be launched from friendly territory and which have a range of the order of 150 kms.

TABLE 1 - OPTIONS CONSIDERED

	OPTIONS	REMARKS
Line-of-sight or short range systems	. additional army Divisions in reserve	assumed that these can be deployed when and where required but engage WP forces in meeting engagements (1:1 exchange ratio).
	. augmentation of Divisions with MLRS Phase III and RPV target acquisition systems	assumed that will not cause WP to increase his strength in holding, sectors
	. aircraft penetrating and attacking with line-of-sight weapons	F16 type aircraft assumed, carrying 4 dispensers each carrying 40 TGSMs.
Stand-off systems	. ATACMS type system, deployed in each corps sector	assumed 150 kms range enabling support to be given to adjacent corps
	. aircraft with long range stand-off weapons	F16 aircraft assumed carrying 4 stand-off missiles each equivalent to one ATACMS missile.
	. target data provided from a stand-off radar system	assumed that extra JSTARS are provided for targetting with 2 orbits covering the Central Region.

All the cost and effectiveness data used for these options is an Annex to this paper. It must be pointed out that some difficulty was found in assembling this data, particularly at an unclassified level, and therefore too much weight should not be put on the actual numbers used. If the reader has numbers that he would prefer to use, then the calculations are easy to revise.

5.0 COMPARISON OF RELATIVE COST EFFECTIVENESS OF LAND AND AIR OPTIONS

5.1 Approach

Let us concentrate first on the case shown in Figure 3 where forward NATO forces are in a good defence posture but reserves are all engaged in 'meeting' engagement. A sum of $30 billion spread over 15 years will be assumed to be available for augmentation to NATO Central Region defence. A conventional war of 6 days duration will be assumed.

5.2 Line-of-sight of Short Range Systems

Figure 4 compares the three options listed in Table 1.

Adding extra Army divisions in reserve is clearly an unattractive way of increasing NATO's capability, even assuming the additional manpower is available, and will not be considered further. It was included largely to give a point of reference.

Adding MLRS Phase III to all the corps sectors gives a contribution which reduces as the number of WP main thrust sectors reduces. This is because the limited range of MLRS does not enable cross-corps support to be given and because of the implicit assumption that MLRS is only effective against forces in the open and on the offensive - i.e. those forces in the main thrust sectors.

Because attacks by aircraft can be concentrated into the main thrust sectors their effectiveness is independent of the number of these sectors. Two lines are shown in Figure 4 one for 3% attrition and the other for 10%.

Comparison of MLRS and aircraft illustrates the importance of the flexibility of air which enables it to be brought to bear where needed. However the choice between aircraft and MLRS depends largely on what attrition rate is expected of aircraft penetrating enemy airspace.

5.3 Stand-off Systems

Figure 5 shows a similar picture for stand-off systems. A JSTARS-type target acquisition at a cost of $9M has been assumed to be dedicated to these stand-off systems. Thus only $21B of the $30B is available for ATACMS or aircraft with stand-off missiles.

With the wider cross-corps support provided by the 150km range assumed for ATACMS, this system is much less susceptible to the number of thrust sectors than MLRS. However simple geometric considerations show that with batteries of 9 launchers uniformly distributed across the Central Region, and with launchers set 50km behind the FLOT, cross corps support at 30-80km ahead of the FLOT starts to fall off with less than 4 major thrusts into corps sectors.

If aircraft launch stand-off missiles from within friendly territory, and hence suffer no attrition, and can operate anywhere across the Central Region, they are of similar cost-effectiveness to ATACMS. Their advantage however starts to show when they are required to concentrate in one or two sectors.

5.4 Other Scenarios

Figures 4 and 5 have used as a baseline the current threat with prepared defences line from Figure 3. For a possible future conflict with fewer forces but prepared defences, we might expect the same increments in capability with all the systems considered above (always assuming that sufficient targets can be found and engaged in a timely manner). Thus, in relation to the forces deployed, these contributions would pose a substantial deterrent .

For surprise attacks it may be that MLRS and ATACMS systems would still be deploying. Here aircraft would have a big advantage, assuming their airbases were not closed by enemy pre-emptive action.

6.0 DISCUSSION

Figure 6 presents the results from Figures 4 and 5 in a more directly comparable form. It needs to be reiterated that these results are dependent upon a number of uncertain assumptions and data: however I have tried to be consistent between systems so as to make a fair comparison.

If we believed that aircraft attrition could be kept as low as 3%, penetrating aircraft would clearly be the best option. Moreover they would have the added advantage of a more rapid response to a surprise attack when land-based systems might still be deploying. However analysis suggest that even with an expensive package of defensive aids, aircraft attrition could be high. But these analyses involve a lot of uncertainties, and we may not know how vulnerable aircraft are until a war starts. Some insurance is therefore necessary in case attrition on the day should be high.

Such insurance could be provided by provisioning a stock of stand-off missiles for these aircraft. But now the weak link is the potential vulnerability of the JSTARS system which provides targetting data for mobile targets. This could be avoided by equipping the missiles with search sensors (to do the same job as the pilot). Figure 6 suggests that even if this increased the missile cost by 50% this could still be worthwhile.

But aircraft are vulnerable on their airbases, particularly to a pre-emptive strike in a surprise attack and may therefore not be available when needed.

MLRS is clearly very cost-effective as a divisional asset and with its own dedicated RPV target acquisition is reasonably robust. However its cross corps flexibility is poor. ATACMS offers greater cross-corps flexibility but the higher cost of its longer range missile largely offsets this advantage. Purchase of ATACMS would therefore have to be on its ability to engage deeper targets rather than to provide cross corps support, but the value of this has not been measured in this simple analysis. The same comments on target acquisition apply to ATACMS as to aircraft with stand-off missiles.

It seems evident from this discussion that there is no system that is obviously best in all circumstances. Nor with the various uncertainties involved is it possible to derive a best mix of systems.

7.0 CONCLUSIONS

- There is no obvious best system or mix of systems.
- Perhaps the most critical factors in comparing land and air options are:
  - attrition of aircraft penetrating enemy airspace
  - costs and vulnerability of target acquisition systems for long range stand-off missiles
  - a comparable basis for air and land system life cycle costs
  - setting a value on the wider flexibility of air to penetrate in depth and to operate in other roles and outside the NATO Central Region.
- My belief is that we shall never be able to derive definitive and convincing values for these factors.

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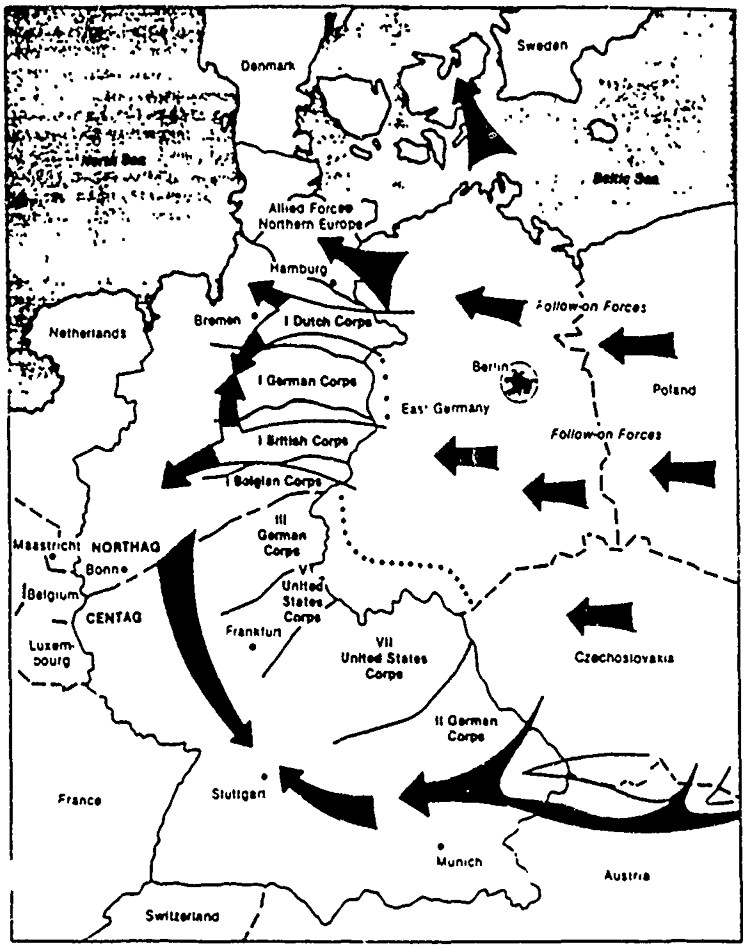


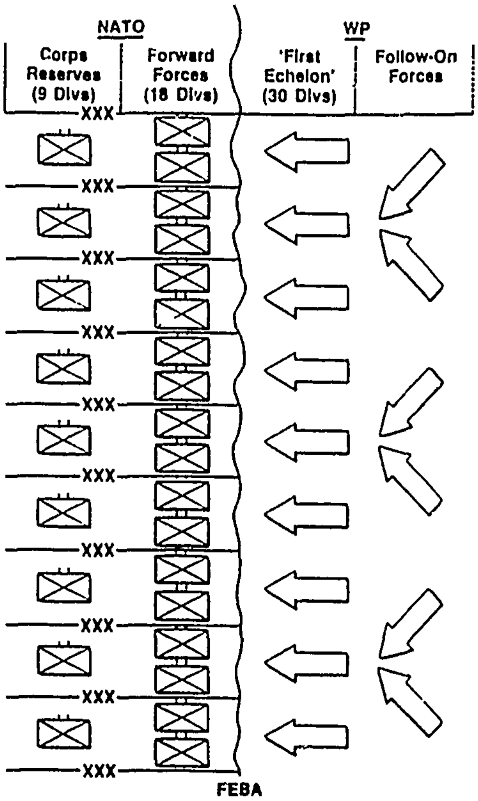


Fig. 1 -Warsaw Pact Offensive

Fig. 2 - A Possible Force Deployment

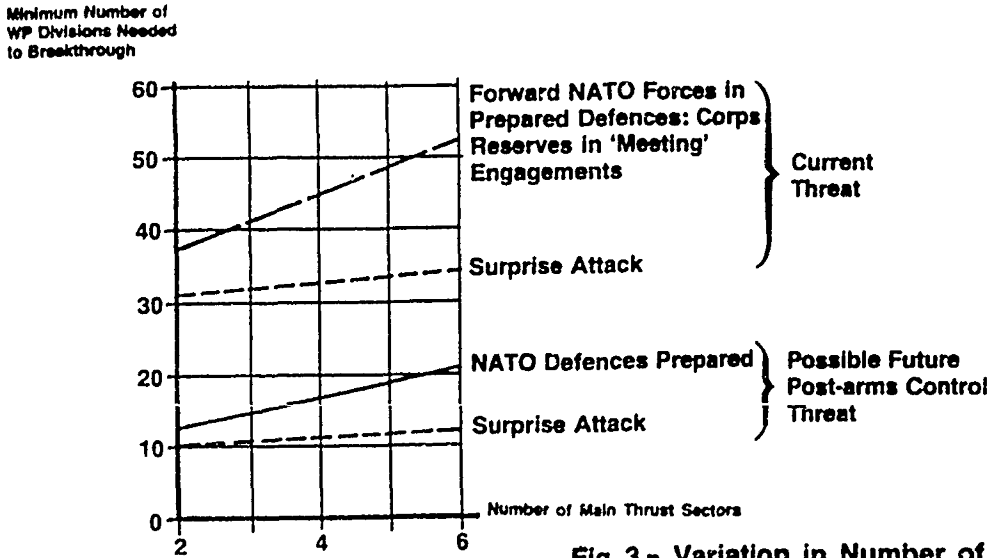


Fig. 3 - Variation in Number of WP Divisions Required to Breakthrough

Fig. 4 – Comparison of the Effectiveness of Army Reserves, MLRS, and Aircraft with Line of Sight Weapons [$30B Cost]

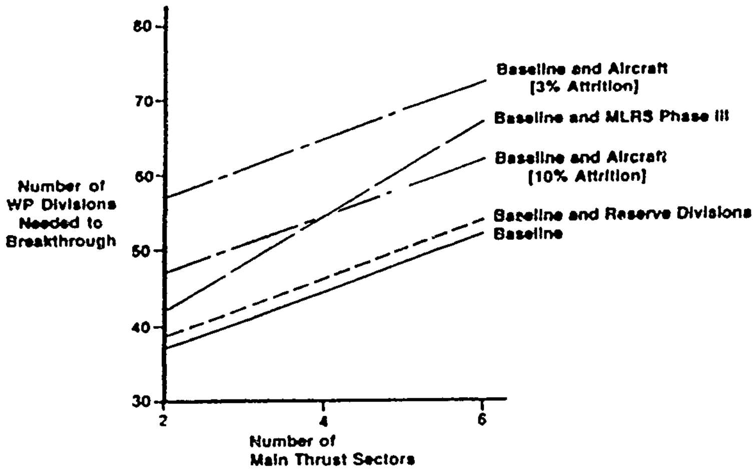


Fig. 5 – Comparison of the Effectiveness of Stand-off Systems [$30B Cost]

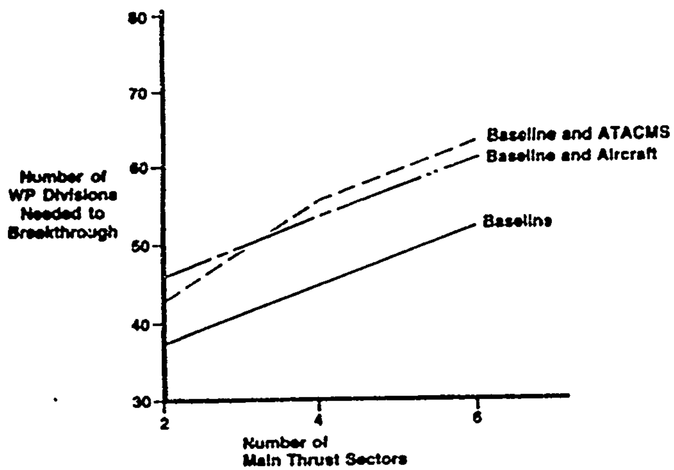
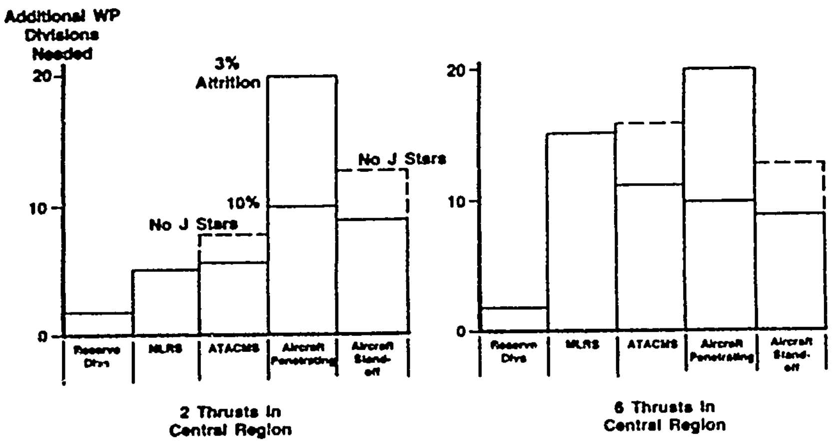


Fig. 6 – Comparison of the Effectiveness of Systems for Constant 15 Yr Cost



DATA USED ANNEX A

A.1 Cost Data

A rate of exchange of 1.6$/£ has been used to convert all prices to $.

It is assumed that a sum of $30B spread over 15 years for equipment and support is available to augment NATO Central Region defence.

A.2 Army Divisions in Reserve

A.2.1. Costs

Reference 6 gives the cost of UK forces in 1(BR) Corps as £2358M which includes provision for some new equipment. This is for 3 divisions. Hence the cost per division is about £730M, giving a 15 year cost of £11B ($17B).

A..2.2 Effectiveness

It will be assumed that the extra divisions can be used when and where required, but will not have time to deploy defensively and will therefore engage WP forces in meeting engagements. Thus each reserve division deployed will require the WP to commit one extra division to achieve a breakthrough.

A.3 Ground Launched Missile ("ATACMS")

A.3.1. Costs

References 7 and 8 give a unit acquisition cost for an ATACMS missile of about $.50M. If the unguided warheads are replaced by TGSMs, the cost will be considerably higher. Assuming a TGSM cost of $50,000 per unit and assuming that 20 are carried, the overall cost per "smart" ATACMs would be about $1.5M.

Costs of a launcher and its slice of support (logistic) vehicles is not known, but $2M seem not unreasonable.

On the basis of artillery regiment manning, about 40 men per launcher will be needed for the launcher, logistics and regimental organisation supporting it. At say $30K per man year, this gives $18M 15 year cost for manning.

For an organisation, as suggested in Ref. 9, of 18 launchers per corps sector (organised in batteries of 9), an investment of $30B over 15 years could provide:

18 x 9 launchers + manpower	=	$3.24 B
Target acquisition JSTARS (para A.6.3)	=	9
11840 missiles at 1.5M each	=	17.76
		30 B

Thus each launcher would have 73 missiles allowing an average of 6 fire missions per day (2 missiles each) over a period of 6 days. This is well within the launcher utilisation rate.

However launchers will be vulnerable to counter-battery fire and to attack from aircraft when moving between fire positions. For 97% survival probability per launcher per fire mission, only some 62% of the missile stock would be fired. This situation could be recovered by provisioning one replacement launcher for every one operational launcher. Since the launcher costs are not significant in relation to the missile costs, this could be done with little change to the missile stockpile (reduce to 11608).

A.3.2. Effectiveness

Assume that the surveillance, target acquisition and guidance can ensure that the weapon footprint encompasses a target of suitable size (reference 10 suggests a footprint of 400m radius, and so this would cover a line of 16 vehicles at 50m spacing). Using the "guesstimates" of Reference 11 we could calculate the number of vehicles killed in the group with a single weapon in the following way:

SUB SYSTEM CHANCE OF SUCCESS

Bus vehicle	
Arrival over designated target area (allows for failure, enemy action en-route).	.85
Probability that target still in designated area	.70
Successful burst and dispense	.90
Thus: Chance of bomblet launch into area containing target	.54
Submunitions	
Initiation of smart bomblet guidance	.90
Initial trajectory within scope of guidance system	.80
Successful hit	.60
Thus: hit probability	.43
Firepower kill given a hit	.30

Thus per successfully delivered missile of 20TGSM's we might expect 20 x 0.3 x .43 = 2.6 vehicle kills

For a Warsaw Pact Division containing some 3000 vehicles (400 AFV, + 2500 support vehicles (Reference 9)), and assuming that the submunitions cannot discriminate between trucks and tanks, then to kill a division (i.e. reduce it to 50% strength) would require 576 weapons successfully delivered and optimally targetted, or 1068 weapons launched (576/0.54).

(Whilst it is recognised that killing a division in this way is probably not feasible because of the weight of fire involved and the overkill effects, it does nevertheless provide a comparative measure of the effectiveness, adequate for the present purposes).

A.4 MLRS Phase III

A.4.1. Costs

Reference 7 gives the cost of an MLRS Phase I missile as $13,000. Thus using the cost assumed in para A.3.1., the cost of a pod containing 6 missiles each with 6 TGSMs would be $1.88M.

Since proposals for ATACMS involve the use of MLRS launchers, we can use the same costs for these as in para A.3.1. Thus:

18 x 9 launchers + manpower	=	$3.24 B
RPV target acquisition system (para A.6.2.)	=	1.14
13,630 pods at 1.88M	=	25.62
		$30B

Thus each launcher would have 84 pods allowing an average of 7 fire missions per day (2 pods each) over 6 days. This is well within the capability of MLRS.

As for ATACMS, launcher costs are relatively small compared to missile costs. Hence some extra money could be diverted to provide replacement launchers to allow for attrition, with little impact on missile numbers.

A.4.2. Effectiveness

For consistency, the same effectiveness calculation will be used as for ATACMS. Thus for a pod of 36 TGSMs, we might expect 36 x 0.3 x 0.43 = 4.6 vehicle kills per pod successfully delivered. Thus to kill a division would require 326 pods successfully delivered or 604 pods launched.

A.5 Aircraft

A.5.1. Penetrating Aircraft

Aircraft Acquisition Costs

Some quoted acquisition costs per aircraft are:

Reference 12	F16C Flyaway cost + spares	=	$21M
Reference 2	F16	=	$17.5M
Reference 6	Harrier GR-5 (£16M)	=	$26M

Hence for this class of aircraft $23M will be assumed.

Aircraft Support Costs

Reference 6 gives the total cost of offensive support as £362M for 1988/89. This is for 5 squadrons of aircraft (i.e. 60 aircraft in total assuming 12 aircraft per squadron (Ref. 13)) But this includes a significant procurement of Harrier GR5. Excludi[illegible] this, the operating cost for the year is about £120M, i.e. £ [illegible] a year per aircraft. Thus for 15 years the support cost is £[illegible]M which is about 2 x the procurement cost. This factor seems consistent with other data and will be assumed here.

Weapon Costs

For aircraft penetrating and using line of sight weapons, it would be feasible to carry 4 dispensers, one on each of the under wing stations and a reasonable payload might be 40 TGSMs per dispenser (i.e. double that of ATACMS since no propulsion is needed). Costs will be largely dictated by the TGSM cost - hence $40 x 50K per dispenser + some additional cost for the dispenser itself giving say $2.2M per dispenser.

The weapon stockpile provided will be pre-determined on the basis of an assumed attrition rate, sortie rate and duration of war. Suppose this is done on the basis of 4 sorties/day over 6 days with 3% attrition, then a dispenser stockpile of 70 per aircraft will be provisioned at a cost of $154M.

Total Costs

Total cost per aircraft over 15 years thus becomes

Procurement of aircraft	$23M
Operating and support	$46M
Weapon stockpile	$154M
	$223M

Thus for \$30B investment, a fleet of 134 aircraft and weapons could be acquired and operated.

A.5.2. Effectiveness

Assume again that the weapons effectiveness is as for ATACMS. Thus every successfully delivered dispenser of 40 TGSMs would kill 40 x .3 x .43 = 5.2 vehicles. Or per successful sortie with 4 dispensers targetted on different parts of the enemy column, 21 vehicles would be killed.

The number of dispensers successfully delivered depends on aircraft attrition and on the probability that the pilot will attack the correct target. Over 6 days at 4 sorties a day starting with 134 aircraft, the total number of sorties arriving in the target area are (assuming all attrition occurs before weapon release):

2247	for	3% attrition
1110	for	10% attrition

Following para A.3.2., we could reasonably suppose a probability that the pilot will find the target of 70% and a probability of the dispenser successfully dispensing of 90%. Hence the successful missions become:

1416	for	3% attrition
699	for	10% attrition

A.5.2. Stand-Off Aircraft

Costs

For aircraft operating from stand-off, we could assume that, if the aircraft is weapon station limited, only 4 stand-off weapons can be carried. Assume these are similar to ATACMS missiles and hence cost \$1.5M each and carry 20 TGSM each.

Whilst a high sortie rate might be feasible because of the shorter distance flown than if the aircraft has to penetrate, the probable need to loiter to wait for targetting information is likely to restrict the sortie rate. Therefore assume 4 per day as for penetrating aircraft. A weapon stockpile for 6 days with zero attrition rate would be 96 per aircraft. Costs per aircraft are thus:

Procurement	\$23M
Operating & support	46
Weapons	144
	\$213M

Since targetting information will need to be provided (as for ATACMS), an investment of $30B over 15 years could provide:

Target acquisition (JSTARS para A.6.3.)	=	$9B
98 aircraft and weapons	=	$20.8B
		$30 B

Effectiveness

Following the ATACMS calculations for 4 weapons launched the kills would be

$$4 \times 20 \times 0.3 \times .43 \times .54 = \underline{5.6} \text{ vehicles}$$

Since the aircraft only operate over friendly territory, attrition can be assumed to be zero hence over 6 days 98 aircraft would carry out 2352 sorties.

A.6 Target Acquisition

A.6.1. General Comments

It is assumed that a surveillance system is in place, perhaps based on JSTARS, which gives broad cueing to dedicated target acquisition sensors. Only the cost of providing these dedicated sensors will be attributed to the weapon systems being considered here.

For aircraft which penetrate and attack with line-of-sight weapons, the pilot will search for and acquire targets. However for missiles with no autonomous search capability, targetting information is required before launch. For MLRS it is assumed that this will be provided by RPVs dedicated to the MLRS batteries. For the longer range ATCMs and aircraft launched stand-off missiles, additional JSTARS dedicated to targetting, are assumed to be purchased.

A.6.2. For MLRS

Reference 14 gave the procurement cost for each AQUILA RPV as $890K.

An RPV organisation to support 18 launchers per Corps could be for one RPV section to support each troop of 3 launchers (i.e. 6 RPV sections). Assume 1 ground station per RPV section. The number of air vehicles needed is governed by attrition expectations and provision of 100 vehicles per Corps would not be unreasonable.

Following the data in Reference 15, we obtain per Corps:

100 air vehicles	$89M
15 yr operating cost	30
6 ground stations	6
15 yr operating cost	2
	$127M

Or for the Central Region, a cost of 9 x 127 = $1.14B.

A.6.3. For Stand-Off Missiles

Assume one orbit in NORTHAG and one in CENTAG for a JSTARS systems dedicated to targetting. Assume 5 aircraft to keep one on orbit, with some allowances for attrition (i.e. 10 aircraft required).

Reference 2 quotes $300M procurement cost per JSTARS, and Reference 17 gives $330M. Reference 6 gives support to these figures by quoting £150M ($240M) for an E3 AEW aircraft. Taking a 15 yr operating cost as 2 x procurement cost, this gives the life cycle cost of aircraft for the Central Region as $9B. To this must be added tne cost of ground stations but this is likely to relatively small (Ref. 2 gives a procurement cost of $730M for 95 Ground Support Modules and Ref. 16 $1.1B for 100).

Force Modernization Analyzer (FOMOA)

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The purpose of this paper is to describe an optimization model which was developed to support the Force Modernization Analysis undertaken by the Department of the Army, Office of the Deputy Chief of Staff for Operations and Plans (ODCSOPS). Force Modernization Analysis forms an integral part of the long-range planning and strategy for investment and acquisition of weapon systems. This paper is concerned with the Aviation Modernization Acquisition Strategy and is illustrative of the use of the model for other systems. The model was developed with the intention of making it

(1) Simple,
(2) User friendly,
(3) Provide quick turn around analysis,
(4) Adaptable to other weapon systems, and
(5) Capable of evaluating alternative investment and acquisition strategies.

The Model

The model is implemented on an Microsoft® Excel based spreadsheet using an optimization package called Super MacVINO®. We run the model on a Macintosh™ II or on a Macintosh SE, equipped with a Radius Accelerator 16™, (a 16MHz, 32 bit microprocessor for speed enhancement), and a MC68881 floating-point co-processor. Super MacVINO is a linear programming optimizer with capability to solve mixed integer (0/1) problems. Hardware and software required to run Super MacVINO are given below.

(1) A Macintosh Plus, SE, or II with at least 1 Mb of memory

(2) One 3.5 inch microdiskette drive, or a hard disk

(3) Microsoft Excel for entering the model data (or any other spreadsheet capable of saving models in 1-2-3 WKS format)

Numerical Input data and the appropriate formulas (objective functions, constraints, etc.) are contained in the model spreadsheet.
Super MacVINO reads the input data and converts them into a linear programming format and then tries to optimize the objective function.

The spreadsheet is organized in the following manner:

Rows are used to represent the decision variables (i.e., the number of different types of aircraft purchased each year), and functions of decision variables such as the force composition (purchases + inventory in each year), annual and cumulative costs, annual modernization measures, etc.

Columns are used to represent the planning years (1991 thru 2010)

The spreadsheet layout segmented by rows is given below.

OUTPUT SECTION
Minimum cost or maximum modernization objective functions (See Appendix)
Decision Variables (See Appendix)
The following for each year in the planning period
- Cumulative and annual force (fleet) costs
- Balanced force modernization percentages
- Total procurement, O&M, and fixed costs for force
- Cumulative funding for force

The following for each mission and each year in the planning period
- Total modernization weight and total systems by mission
- Ratios of total modernization weight to total systems by mission (Modernization weight indicates extent of modernization, see appendix for technical definition and use)

The following for each aircraft type and each year in the planning period
- Force composition by type
- Total procurement costs by aircraft type

INPUT SECTION
The following for each year in the planning period
- Funding for force
- Minimum balanced modernization percentage requirement

The following for each mission and each year in the planning period
- Minimum modernization ratio requirement by mission
- Minimum total systems requirement by mission

The following for each aircraft type and each year in the planning period
- Procurement, O&M, and fixed costs by aircraft type
- Modernization weight by aircraft type

The following for each production line and each year in the period
- Lower and upper limits on annual production
- Production line status (open/close)

Starting force composition

CONSTRAINTS
See Appendix

The decision variables are contained in decision cells in the spreadsheet and are flagged for Super MacVINO by unprotecting them. The Objective cell which contains the formula to be optimized, is identified by assigning the name VNMAX or VNMIN depending on whether the user needs to maximize or minimize the formula.

In cost version of the model, the objective cell contains the cumulative cost over the 20 year period and the objective cell for the maximization version contains the maximum balanced modernization for the 20th year.

Results

The model was developed and tested using the aviation modernization data given in the AAMTOR study which uses the PHOENIX model for minimizing the sum of annual costs and penalty costs for violating resource and policy constraints. PHOENIX is a complex linear optimization model which can solve mixed integer problems. It runs on a main frame and was developed by U.S. Army Concepts Analysis Agency and the Naval Postgraduate School.
Super MacVINO which drives the spreadsheet model solved both versions of the optimization problem in approximately 70 minutes without the Radius Accelerator, and with the accelerator, it took about 20 minutes.
The cost minimization results generated by the spreadsheet model for the 20 year planning period were generally consistent with those reported in the AAMTOR study.
The maximization version of the model which measures the extent of possible modernization in the least modernized mission under funding constraints is unique to the spreadsheet model. This feature allows the user to perform trade-off analysis between investment and modernization (i.e., for a given investment, it achieves the maximum modernization).
A wide variety of analyses relating to investment, affordability, cost effectiveness can be carried out using this model. Turn around time is minimal which can be important to the user.

Conclusion

The spreadsheet model provides an analytical tool to conduct quick response macro analysis pertaining to force modernization planning. A user without any special training or skills can learn to to operate the model in a few sessions. The mechanics of the model are easy to understand. The data entry is the only time consuming part compared to the actual running of the model.
The model will be used to perform modernization analysis relating to other systems such as Heavy Forces, Fire Support, etc.

Acknowledgment

We thank Mr. E. B. Vandiver III, Director, U. S. Army Concepts Analysis Agency for initiating this effort, in particular for calling our attention to the PHOENIX model and suggesting the spreadsheet approach to modernization analysis. We are grateful to Mr. Daniel J. Shedlowski and Colonel Milivoj Tratensek for valuable guidance and support throughout the development of this project. We appreciate the cooperation from Lt Colonel (retired) William R. Teufert and Major Robert B. Clemence in providing us with aviation data and insights into the PHOENIX Model. We would also like to thank Dr. Jerome Bracken for providing early outside review and constructive comments

APPENDIX

Mathematical Representation of the Model

Index variables.

i: Aircraft mission/role (attack, scout, utility, cargo), where i = 1,4.

j: Aircraft type within a mission where $j = 1,2,3,\ldots\ldots\ldots,n_i$, and n_i is the number of different types of aircraft in mission i (e.g. AH-1S, AH58D, AH-64, LHX_ATK in mission 1).

t: Planning year (e.g., t = 1, for 1991, t = 20 for 2010)

p: Index for production line, where p = 1,6 (The current version of the model has 8 high technology aircraft types. There are two common production lines, one for the AH58D, OH58D pair and another for the attack and scout LHX. The other four initially high technology aircraft, each with their own production line, are the AH64, UH60, UH60B, and CH47D. There are 11 types of "low" technology aircraft in the model.)

Decision variables.

X_{ijt}: Number of aircraft in mission i of type j purchased in year t.

Y_{ijt}: Number of aircraft in mission i of type j inherited in year t.

MR: Balanced Maximizer

Explanation of MR

The decision variable MR is the objective function in the maximization version of the model. Its value is decided by the maximization process and the constraints given by

$$MR \leq \frac{HT_{i(20)}}{M_{i(20)}} \quad \text{where } i=1,4$$

$HT_{i(20)}$ is the total modernization weight of the aircraft in mission i in year 20. That is

$$HT_{i(20)} = \sum_{j=1}^{n_i} E_{ij(20)}(X_{ij(19)}+Y_{ij(20)})$$

where $E_{ij(20)}$ is the modernization weight in year 20 for the aircraft in mission i of type j. This weight is a user input value between 0 and 1. High technology aircraft have weight 1, completely obsolete aircraft have weight 0.
The "19" in a subscript is because of lag as explained below.

$M_{i(20)}$ is the total number of aircraft required in mission i, in year 20.

Thus after maximization MR is the minimum of the ratios over the 4 missions of the total mission modernization weight of the aircraft in the last (20th) year to the mission total requirement in the last year. That is MR attains the value:

Min $(HT_{i(20)}/M_{i(20)},\ i = 1,4)$

As a check this minimization function is included as a post processor function in the spreadsheet. (Modernization weight is defined and used below more generally for any planning year t, not just the last year.)

Input data needed in cost minimization objective discussion.

C_{ijt}: Purchase cost of aircraft in mission i of type j in year t.

OM_{ijt}: O&M cost of aircraft in mission i of type j in year t.

FC_{pt}: Fixed annual cost of high technology production line p in year t

Z_{pt}: Open/close production line status in year t for high technology aircraft line p. If the production line is open, the value is 1, 0 otherwise.

Objective function for minimum cost version.

Minimize total cumulative cost over the planning period (20 years).

$$\text{Minimize} \sum_{t=1}^{20} \left(\sum_{i=1}^{4} \sum_{j=1}^{n_i} \left(X_{ijt}C_{ijt} + (X_{ij(t-1)}+Y_{ijt})OM_{ijt}\right) + \sum_{p=1}^{6} FC_{pt}Z_{pt} \right)$$

Additional input used in constraints below:

M_{it}: Total number of required aircraft in mission i, in year t.

E_{ijt}: Modernization weight, for the aircraft in mission i of type j in year t. Fully modernized aircraft have weight 1, completely obsolete aircraft have weight 0,

R_{it}: Minimum fraction modernization required in mission i, in year t.

FL_t: Funding level for year t.

B_t: Balanced modernization level for year t.

LP_{pt}: Lower annual production limit for line p in year t.

UP_{pt}: Upper annual production limit for line p in year t.

Q_{ijp}: Aircraft production line assignment indicator for high technology aircraft in mission i of type j and line p. A value of indicates p is the production line for the aircraft . The indicator has value 0 otherwise.

ST_{ij}: Inherited assets for t=1, (starting year), and new items produced the previous year.

Constraints.

The optimization process is subject to:

(1) Annual funding constraints.
(Generally not used in cost minimization cost runs.)

$$\sum_{t=1}^{T} \left(\sum_{i=1}^{4} \sum_{j=1}^{n_i} \left(X_{ijt}C_{ijt} + (X_{ij(t-1)}+Y_{ijt})OM_{ijt} \right) + \sum_{p=1}^{6} FC_{pt}Z_{pt} \right) \leq \sum_{t=1}^{T} FL_t$$

for T = 1,2,...,20

(2) Annual balanced modernization constraints.
(Generally not used in modernization maximization runs.)

$$\sum_{j=1}^{n_i} E_{ij(t)}(X_{ij(t-1)}+Y_{ijt}) \geq B_t M_{it} \qquad \text{for } i = 1,2,3,4$$

t = 1,2,...,20

(3) Minimum total requirements by mission.

$$\sum_{j=}^{n_i} . \acute{}_{ij(t-1)}+Y_{ijt}) \geq M_{it} \qquad \text{for } i = 1,2,3,4$$

t = 1,2,...,20

(4) Minimum modernization fraction requirements by mission.

$$\sum_{j=1}^{n_i} E_{ijt}(X_{ij(t-1)}+Y_{ijt}) \geq R_{it} \sum_{j=1}^{n_i} \left(X_{ij(t-1)}+Y_{ijt} \right) \qquad \text{for } i = 1,2,3,4$$

t = 1,2,...,20

(5) Lower and upper annual production constraints for line p in year t.

$$LP_{pt} \leq \sum_{i=1}^{4} \sum_{j=1}^{n_i} Q_{ijp}X_{ijt} \leq UP_{pt} \quad \text{for } p = 1,2,\ldots,6$$

$t = 1,2,\ldots,20$

(6) Constraints on inheritance decision variables (Y_{ijt}) for all aircraft types

$Y_{ijt} \leq ST$ for $t = 1$

$Y_{ijt} \leq Y_{ij(t-1)}$ for $t = 2$

$Y_{ijt} \leq X_{ij(t-2)} + Y_{ij(t-1)}$ for $t > 2$

(7) In addition for maximization runs there are the constraints discussed in paragraph 3, which with the decision variable MR, drive for maximum balanced modernization in year 20.

Where the subscript "t-1" occurs in the procurement variable "X" in the minimum cost objective and some constraints above, it is to account for the one year lag between the purchase year and the operational year. For some aircraft, there is a 2 year lag. Thus for full generality, "$X_{ij(t-1)}$" should be replaced by "$X_{ij(t-G_{ij})}$", where G_{ij} is the lag for the aircraft in mission i of type j.

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CREW REQUIREMENTS DEFINITION SYSTEM (CRDS) DEMONSTRATION

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ABSTRACT

The crew requirements definition system (CRDS) is a computer-based methodology designed to minimize the time required to accomplishment any set of tasks while using the fewest resources. It enables analysts and researchers to study in a timely and cost effective manner the effects of varying crew size, task start times (and hence task sequencing), and task allocation to crewmembers or equipment items during the performance of designated missions without the need to observe crews actually performing their duties.

The CRDS is programmed in C-language and is designed to be used on an "XT" or faster class of personal computer. The basis of the system is several automated PERT, GANTT, and critical path method calculations. In addition, the system produces other automated calculations and summaries to aid the user. The user should have some knowledge of these operations research techniques to use the system effectively. Also needed is an understanding of the tasks to be performed, the personnel and equipment items available to perform the tasks, each task's duration, and any requirements for task sequencing.

CRDS is useful in any military or civilian situations in which there is a need to design and evaluate alternative small unit organizational structures. The system can be used whenever the user has some knowledge, or is willing to venture some guesstimate, of the tasks that need to be performed and the capabilities of various assets to perform those tasks.

In this session, the background and status of the CRDS are briefly described, as are its benefits that can be derived from its use. However, the major objective of this session is a demonstration of each major component and function of the system. The demonstration will use examples taken from the results of pilot studies of CRDS.

SELECTION BOARD SUPPORT SYSTEM:

AN INDEPENDENT EVALUATION

by Colonel Gordon W. Arbogast and
Captain Robert H. Acker

INTRODUCTION

Promotion is a very sensitive issue among the Army's commissioned officers. Failure to achieve a promotion with peers implies below average performance. A second failure to achieve the same grade leads to separation from active service. Selection for promotion is extremely competitive. Those who have served on promotion boards agree that there is only a small percentage of the eligible population whose records are clearly substandard. Likewise, only a small percentage of the records are clearly superior to the rest. Most of the records require a very close scrutinization in order to distinguish one record from another. The number of promotions for a given grade is limited by law. Thus, the Army directs a board of senior officers to perform the scrutinization necessary to select a limited number of officers for promotion. Ultimately, the selection process identifies those officers who become generals, those who are retained in the officer ranks for 20 years or more and become eligible for retirement benefits, and those who will be separated from military service. The decisions made by selection boards affect the careers of every Army officer. The impact of the selection process requires that the Army be extremely careful in the development of a fair and reliable selection system.

In 1983 the Army began to question the need to improve its selection process. A panel of General Officers identified as the Blue Goose Work Group was tasked to review the current selection procedures and policies. The panel recommended a series of changes to the existing manual procedures which led directly to the development of a new system designed to enhance the quality of decision making in the selection process. This system was built around Multiple Attribute Decision Modeling (MADM) and was named the Army's Selection Board Support System (SBSS). Designed to improve a board member's consistency of judgment, SBSS is a Decision Support System that can be used for all officer selection boards i.e. command, schooling and promotions. By March 1987 the Total Army Personnel Agency (TAPA), formerly the Military Personnel Center (MILPERCEN), had already done a great deal of research in the development and evaluation of SBSS, however an independent evaluation was sought. This evaluation was agreed upon by TAPA and the Department of Engineering of the U.S. Military Academy. The purpose of this paper is to describe the Selection Board Support System, identify the advantages and disadvantages of this proposed system over the current system, and describe some alternatives to the proposed selection system.

THE CURRENT SELECTION PROCESS

The basis of the current selection process is the subjective evaluation of officer files by a board of senior officers. The typical board consists of three panels of six members. Each officer file includes: a current full length photograph; a complete set of Officer Evaluation Reports (OERs) provided on microfiche; and an Officer Record Brief (ORB) which provides a complete history of the officer's career including assignment history, awards, civilian education, and military education.

The selection process requires that each board member evaluate every file and assign a singular numerical score from 1+ to 6-. Although general guidance is given to the board members regarding the criteria to base numerical evaluations, board members are essentially free to develop the basis of their evaluations. Scores are written on a vote sheet attached to each officer file. Successive evaluators may review scores already assigned to the file during "open voting" sessions, but are asked not to look at previously recorded scores during "blind voting" sessions to avoid biased judgements. Despite these instructions, the method of recording votes permits board members to bias their scores by viewing the vote sheet.

After each member of a panel has voted the file a total panel score is determined using a modified Borda technique (adding the scores of each panel member). A panel Order of Merit List (OML) is established based on the panel scores. The Board OML is then established by combining the three panel OMLs, again using a modified Borda technique, adding the rank order from each panel and sorting low to high. A "cut line" is drawn based on the number of promotions dictated by the Department of the Army. Specialty floors and affirmative action goals are then checked. Floors or goals which are not met require relief from Department of the Army or adjustment of the rank order until the floors and goals are met.

THE PROPOSED PROMOTION PROCESS

The proposed selection process, the Selection Board Support System (SBSS), is a modification of the current process. SBSS is a decision support system designed to improve and automate the selection process for promotion, command, and school. Like the current process, the basis for selection is the subjective evaluation of officer files by a board of senior officers. The major difference from the current process is the application of Multiple Attribute Decision Making. Instead of assigning a single score to each file, the evaluator explicitly evaluates the file for each of several criteria. The evaluator's order of merit list is then developed from these scores and the relative weight he assigns to each of the criteria.

Surveys conducted by MILPERCEN of officers in the field have indicated a strong confidence in the current selection board process. However, board members who have experienced the grueling task of evaluating thousand of files over a four to six week period have indicated a concern for evaluator consistency. The factors which influence consistency include fatique; the time span of the board process; and the amount of information which must be considered for a single evaluation. Thus, the concern for voter consistency was the driving force for the development of SBSS.

The SBSS prototype was ready for testing in 1985. MILPERCEN conducted the SBSS Experiment using the most experienced board members of the 1985 colonel promotion board to evaluate a sample of seventy files. A perfect rank order of the seventy files was established as a benchmark. Then the seventy files were rank ordered using the current selection process and SBSS. The correlation of the SBSS rank order to the benchmark was 97% while the correlation of the current process to the benchmark was 94%. Subsequent to the SBSS Experiment, steps were taken to develop the software and purchase the hardware for SBSS. Although the SBSS software and hardware is currently in place and running, it has not replaced the current selection process.

How does SBSS work? SBSS employs management science techniques not only to automate the process, but also to provide a structured environment for the evaluator. The management science techniques included in the SBSS software consists of three algorithms: Saaty's Eigenvector approximation which helps the board member develop criteria weights; the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) which develops the rank order of officer files for each board member; and Borda which develops the board OML by combining the OMLs of each evaluator.

The major inputs to Selection Board Support System can be divided into three categories: data from officer records, the Army's criteria for selection, and individual board member inputs. Data from officer records include a summary of each officer's career (Officer Record Brief) and the critical record of Officer

Efficiency Reports (OERs). The outputs are the individual evaluator order-of-merit lists (OMLs) and the board's cumulative OML.

Insert Table 1 Here

A key new feature of SBSS involves the Army's selection of specific criteria that must be independently evaluated on each officer. For the typical promotion board, these criteria are physical readiness and military bearing, military education level, civilian education level, assignment history and duty performance. The latter is typically considered the most important, but prior to each officer's file being reviewed, each evaluator must develop criteria weights which reflect his opinion of the relative importance among criteria. Thus, each board member introduces his personal value system into the selection process. This is done by employing the first algorithm from T.L. Saaty, i.e. pair-wise comparisons between each criteria and use of the Analytic Hierarchy Process to develop a criteria weight set.

Saaty's method requires the evaluator to compare the relative importance of each pair of criteria and indicate the relative difference on a scale of 1 to 9. A consistency score is indicated to insure that an inconsistent set of input, below 90%, is rejected. SBSS also allows the evaluator to input his importance weights directly. However, this assumes that the evaluator can assess the relative importance among five criteria at once. This is analogous to dividing a pie chart into five areas. The system does allow the evaluator to modify those weights obtained using the pairwise comparison.

After deriving the criteria weights each board member begins to evaluate each individual officer's files. Each evaluator must assess a score for each file in each criteria. The scoring is based on an absolute scale of 1 to 9, which is very general in nature so that it is applicable for each criterion. An example of the scale is shown below.

Very Low   Low   Average   High   Very High
.....1.....2.....3.....4.....5.....6.....7.....8.....9.....
Not Qual   Not Qual   Qualified   Select   Above Contemp

Before a score can be given, the evaluator should define his scale for the given criteria. An evaluator's scale for Civilian Education Level <u>may</u> be defined as follows:

Very Low   Low   Average   High   Very High
.....1.....2.....3.....4.....5.....6.....7.....8.....9.....
HS   Assoc   Bachelor   Masters   PhD

Table II is an example of Board Member A's representative weight set (in parenthesis) along with scores he (she) voted officers 1, 2, 3 ... m.

Insert Table 2 Here

The second algorithm comes into play as each board member attempts to create his own OML. SBSS employs a mathematical algorithm known as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for this purpose. This method is based on the concept that the most desired alternative (i.e. the best officer) of any given set of alternatives (all officers before the board) should be closest to the ideal solution and farthest from the worst-case (negative ideal solution). Euclidean distance is used to measure the actual numerical distance of any alternative (e.g. an officer's score) to the ideal and negative ideal solution. With five criteria, this measure is calculated in five dimensional space. The relative closeness of any alternative is calculated by:

$$C_i = \frac{S_i^-}{S_i^+ + S_i^-} \qquad 0<C_i<1 \qquad i= 1,2,...m$$

Where S_{i-} = distance between each alternative and the negative ideal

S_{i+} = distance between each alternative and the positive ideal

The various alternatives are then rank ordered based on the largest TOPSIS score (C_i). [1]

MULTIPLE ATTRIBUTE DECISION MAKING by Hwang and Yoon [1].

The last algorithm is used to create the Board's order-of-merit list. This algorithm is called Borda and involves a logical combination of the individual OMLs. The OML sequence number for each officer becomes that officer's Borda score for that voter. A simple sum of all OML sequence numbers for an officer becomes that officer's overall Borda score. The Board's OML results from a sort of the total scores from lowest to highest. Each board evaluator can subsequently change the values of the weights, but it is considered important that each evaluator performs the pair-wise comparisons and be presented with the actual weights using Saaty's process.

Upon arriving at the Board's final OML, specialty floors are checked to insure that sufficient numbers of officers with different skills have been promoted. Thereupon, standard Army sequencing procedures are applied to the subset of officers that are to be promoted e.g. officer's with the longest time-in-grade are normally promoted first. This then becomes the official Army promotion list.

PURPOSE OF THE RESEARCH

The purpose of this research conducted at the U.S. Military Academy was to evaluate the Selection Board Support System: identify the advantages and disadvantages of this proposed system over the current system, describe some alternative algorithms to those currently used within SBSS, and compare the effectiveness of these algorithms to those currently used.

ADVANTAGES AND DISADVANTAGES

In our experiment, each of 70 files were evaluated with and without SBSS by an experienced and inexperienced voter. An "ideal" OML was established as a benchmark for each evaluator through an exhaustive reading and pairwise comparison of each file. A second benchmark was established from the 1983 results of the "Blue Goose Work Group", a board of General officers. We found:

1. The change in voting procedure (i.e. the way that votes are recorded) provided by the Selection Board Support System insures blind voting, one of the two primary objectives of SBSS. The automated process insures that board members can no longer see the evaluations of other board members and thus bias their judgmements.

2. SBSS increases the consistency of board member evaluations. The statistical results from the experiment indicate that the Order of Merit List developed using SBSS is highly correlated to both benchmarks and indicates an improvement over the current selection process.

3. The current manual selection system requires the evaluator to absorb and remember an enormous amount of data from the officer's file before assessing one final score.

4. The current manual system also requires the evaluator to consider simultaneously and mentally combine intermediate

assessments for several attributes (i.e. performance, military education, military bearing, etc.).

5. The mental difficulty of the manual system combined with the time pressure and fatigue can cause evaluator frustration and concern for accurate and consistent file evaluations.

6. SBSS allows the evaluator to concentrate on one attribute at a time and not worry about combining several attributes to attain the final score.

7. In both of the voting systems the evaluator could change his evaluation scale during the voting process and thus cause inconsistent voting between files. The requirement to evaluate an enormous number of files will contribute to the liklihood of this problem. Use of a well defined, written scale helps to eliminate the inconsistency when using SBSS. Although SBSS currently provides a scale on the voting screen (shown below), we found that this scale is not specific enough to prevent or alert the evaluator to a change in how he matches a file to a score.

```
 Very Low        Low       Average      High       Very High
.....1.....2.....3.....4.....5.....6.....7.....8.....9.....
 Not Qual      Not Qual   Qualified    Select    Above Contemp
```

8. The scale shown below was used by one of the experimenters to maintain consistency during file evaluations within the attribute of civilian education. This well-defined scale allowed the evaluator to simply match the data to the scale to determine a score.

Very Low		Low		Average		High		Very High
1	2	3	4	5	6	7	8	9
HS		Assoc		Bachelor		Masters		PhD

9. Specifically defining the scale did not preclude the evaluator from modifying his scale. However, the point of change becomes obvious to the evaluator, so that he can adjust all previous scores appropriately. In order to avoid adjustments, it is advisable to practice voting on a sample of files in order to establish a more permanent scale. This scale defines the values of one specific evaluator and is not intended to be an ideal scale to be used by each board member. The Army's selection process is designed so that each board member may incorporate his own personal value system.

10. TOPSIS can produce results which may be undesirable. The relative order of two officers may reverse as a result of the evaluation on a third officer. For example, in CASE 1 (shown below) the rank order for the first three files would be [C], [B], [A] (assuming equal criteria weights). However, if [A] is revoted, as shown in CASE 2, the rank order becomes [B], [C], [A]. Note that the rank order of [b] and [c] changes because of a change in score of [A].

CASE 1:

	MBPF	MEL	CEL	HIST	PERF
A	5	5	5	2	4
B	5	5	5	5	6
C	5	5	5	6	5
D	5	5	5	5	5

CASE 2:

A	5	5	5	7	4
B	5	5	5	5	6
C	5	5	5	6	5
D	5	5	5	5	5

Psychologically, this is difficult to accept. Yet the TOPSIS algorithm will cause this to occur, since the TOPSIS score is based on the ratio: (distance from the negative ideal) / (distance from the negative ideal + distance to the positive ideal). Since each officer is evaluated on an absolute scale, an officer would not expect his relative rank to another officer to vary based on the scores of a third officer. This problem can be resolved by establishing two false alternatives to represent the positive and negative ideal. In fact, the positive ideal is defined by Hwang and Yoon [1] as "the solution which is composed of all best attribute values attainable. The best attribute values attainable on an absolute scale of 1 to 9 are: (9, 9, 9, 9, 9)." Thus, the positive ideal would be represented by the set of scores: 9, 9, 9, 9, 9. The negative ideal would be represented by the set of scores: 1, 1, 1, 1, 1. Since these two sets represent the two extremes of the scale, the positive and negative ideal would never change. Consequently, this modification insures that the relative position of any two officers <u>would not</u> change due to the scores of a third officer. Although this is not done within the SBSS software, it seems consistent with the authors' (Hwang and Soon) definition. It will also eliminate the problem noted above.

ALTERNATIVE ALGORITHMS

During the initial review of SBSS we questioned the choice of the rank-ordering algorithm, TOPSIS. In fact, we had assumed after the initial demonstration that the rank ordering was done using Simple Additive Weighting (SAW), a rank ordering algorithm which simply takes a weighted sum of the criteria scores of each file and sorts high to low. The rationale provided by TAPA for using TOPSIS was that it is considered to be more robust and therefore less likely to create ties between files.

In addition to the TOPSIS algorithm, we questioned Saaty's algorithm for develping criteria weights. This lead to the design of our experiment. Specifically, we wanted to determine:

1. If Saaty's pairwise comparison is a valid method for determining criteria weights.

2. If TOPSIS is a valid method to determine evaluator OMLs.

In this regard it was hypothesized that each algorithm is valid e.g. TOPSIS is a valid method of determining an evaluator's OML. In order to test these hypotheses it was necessary to identify logical, feasible alternatives for each algorithm. Concerning the development of evaluator weights, policy capturing (PC) was used as an alternative. This technique is relatively new and involves making explicit the implicit values of any evaluator or any group of evaluators. It employs linear regression analysis to derive Beta weights for each attribute. These weights are then used as the attribute weights. In determining an evaluator's OML, simple additive weighting (SAW) is an excellent alternative. In fact, in many Multi-attribute Decision Method (MADM) solutions, simple additive weighting is the normal technique employed.

An alternative algorithm could also be employed to determine the board OML. For example the TOPSIS scores for each evaluator are weighted scores that could be summed to develop the board's OML. But we consider the BORDA technique as the most logical since it ensures that each board member has equal influence on the board OML. The BORDA technique develops a score for each file by adding the rank order, not the TOPSIS score, of the file assigned by each of the board members.

DESIGN OF EXPERIMENT

In order to properly design an experiment it was first necessary to assess what the information requirements were for such an undertaking. It was obvious that it would be best to secure live board information. Fortunately, TAPA was able to make available seventy representative files from a recent Army promotion board to Major. In addition, it provided individual evaluator and board OMLs from a special General Officer panel (Blue Goose panel) that had independently evaluated these seventy files. Thus, the unit of analysis was established as a captain's official personnel file. The Army criteria used to select these officers was the same five criteria that was previously discussed.

The key assumptions made were as follows:

1. The sample of seventy available files was representative of the population.

2. The personnel conducting the research (experimenters) were typical of the evaluators that serve on Army boards.

3. A thorough reading of the files will lead to an "ideal ranking" by the evaluators.

4. Policy Capturing produces Beta weights that reflect the relative importance of each attribute.

There were two experimenters that conducted the research. One was a senior captain who had never sat on a board, and the other was an experienced colonel (06), with five years in grade, who had previously served on promotion boards. Each experimenter used SBSS independently to: (1) develop criteria weights (with Saaty's algorithm); (2) rate all seventy files; and (3) develop an evaluator OML (with TOPSIS). Thereafter, several weeks were allowed to elapse before each experimenter developed an ideal OML. This was done by allowing total access to the officers' files and releasing all time constraints. The two experimenters were free to make comparisons between the files and utilize any technique they desired. The final OML reflected the intrinsic value system of each experimenter.

OMLs were then developed using the following combinations of algorithms:

1. SAATY + SAW + BORDA (SSAW)
2. PC + SAW + BORDA (PCSAW)
3. SAATY + TOPSIS + BORDA (STOP)
4. PC + TOPSIS + BORDA (PCTOP)

Correlation analysis and nonparametric statistical analysis were used in the validation process. Correlation analysis was used to evaluate each of the four alternatives vis-a-vis the ideal rankings of the experimenters (e.g. the hypothesis of IDEAL = STOP). A correlation matrix was derived and tests of significance were conducted on the correlation coefficients. Both Sign Tests and Wilcoxon Matched Pair Tests were employed as nonparametric statistical tests. After each alternative was compared with the ideal, both the correlation and nonparametric tests were repeated to test between the various alternative combinations (e.g. STOP = SSAW).

MODELS

As mentioned earlier the first combination was SAATY + SAW + BORDA (SSAW). The model utilized for this alternative was as follows:

$$Y = W_1 x_1 + W_2 X_2 + W_3 X_3 + W_4 x_4 + W_5 X_5$$

where Y = total score of the rated officer

W_i = weight of criteria i using Saaty's algorithm.

X_i = file score assessed for criteria i.

The experimenter OML is then created by ranking the seventy officer files from the highest to the lowest. For the two experimenters this resulted in the following models:

Experimenter 1 (Inexperienced)

$$Y = (.16)X_1 + (.12)X_2 + (.08)X_3 + (.05)X_4 + (.58)X_5$$

Experimenter 2 (Experienced)

$$Y = (.09)X_1 + (.09)X_2 + (.23)X_3 + (.03)X_4 + (.57)X_5$$

Similar models were derived for each of the other three alternative combinations. With Policy Capturing some small negative weights were realized; these were assumed to be zero. Tests were then conducted on all models.

RESULTS OF TESTING

The first test that was conducted was the non-parametric Sign Test. Ten different tests were performed to test each pair of OMLs i.e. the combined Ideal OML and four alternatives for the two experimentors. Given a null hypothesis that the ratio between OML and OML_2 to the total was equal to .50, the Ideal rankings of the two experimentors compared favorably with each of the four alternatives, viz SSAW, PCSAW, STOP and PCTOP. Concerning tests among the alternatives, only PCSAW = STOP was outside the acceptance range, although only barely.

Insert Table 3 Here

When the more powerful Wilcoxon Tests were run, all combinations were well within the acceptance range.

Insert Table 4 Here

The last test that was conducted used correlation analysis. Each evaluator's Ideal and four alternative scores were correlated with each other. As in the Sign Test, they were also combined within categories and then similarly correlated. In each case strong correlation results were obtained. The lowest combined correlation was .886. The probability that a correlation of at least .886 is obtained when there is no linear association in the population between the two OMLs is < .001.

Insert Table 5 Here

CONCLUSIONS

All alternative combinations were determined to be strongly correlated with the Ideal and with each other. In addition, the Sign and Wilcoxon Tests indicated that little difference (if any) exists between any of the pairs of OMLs investigated. This suggests that all techniques employed in the research were valid i.e. both logical and feasible. Thus, Saaty and TOPSIS may well be valid techniques in SBSS. Conversely, policy capturing and Simple Additive Weighting may well be valid techniques to use in a modified SBSS.

In order to properly assess the value of the various techniques, other considerations must be factored into the analysis. If policy capturing were to be used in lieu of Saaty's algorithm, two immediate problems must be addressed. First, the time required to develop an Ideal OML is significant. In an actual board scenario, members would have to evaluate a subset of the files to arrive at the Beta weights. Given the size of the sample required, the "up-front" time would be excessive when compared with Saaty's technique. Secondly, a better way to treat negative Beta weights would have to be found. Saaty's algorithm normalizes the weights. In employing Policy Capturing small negative Beta weights were set equal to zero with the result that the most heavily weighted criteria (i.e. performance) increased greatly in importance, in some cases into the ninety percent range. It is concluded that these problems need not be faced. Saaty's algorithm produces equally effective results in a much more efficient manner.

In comparing TOPSIS to Simple Additive Weighting, a different conclusion is arrived at. Both produce results that are highly correlated to the Ideal. However, SAW is simpler to understand, and it is better known by board members. In addition, TOPSIS can occasionally produce unexpected results. For example, assume one board member changes his evaluation of Officer X and that these scores influence the evaluator's negative or positive ideal. This change could result in an OML change that reverses the order for officers Y and Z, even though their scores were not revoted. This inconsistency produces some concern, although it is recognized that this would not be a common occurrence. The supporters of TOPSIS argue that it is more robust than SAW, and that SAW does not examine the relative strength of an alternative in two directions, i.e. both the negative ideal and positive ideal. In short, it is concluded that SAW is a valid alternative to TOPSIS.

This research is important to the Army in that it evaluates the selection process that will impact every officer several times in his (her) career. It is important that the Army have confidence in its important management decision to employ more management support systems and quantitative analysis in its important decision-making processes. In summary, all evidence in this research points to concluding that the Selection Board Support System and the technical algorithms withing (SAATY's, TOPSIS and BORDA) provide a significant improvement over the current selectio process. It is recommended that future research be aimed at exploring the trade-off between the robustness and inconsistency when comparing Simple Additive Weighting with the TOPSIS algorithm.

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TABLE 1

THE PROCESS

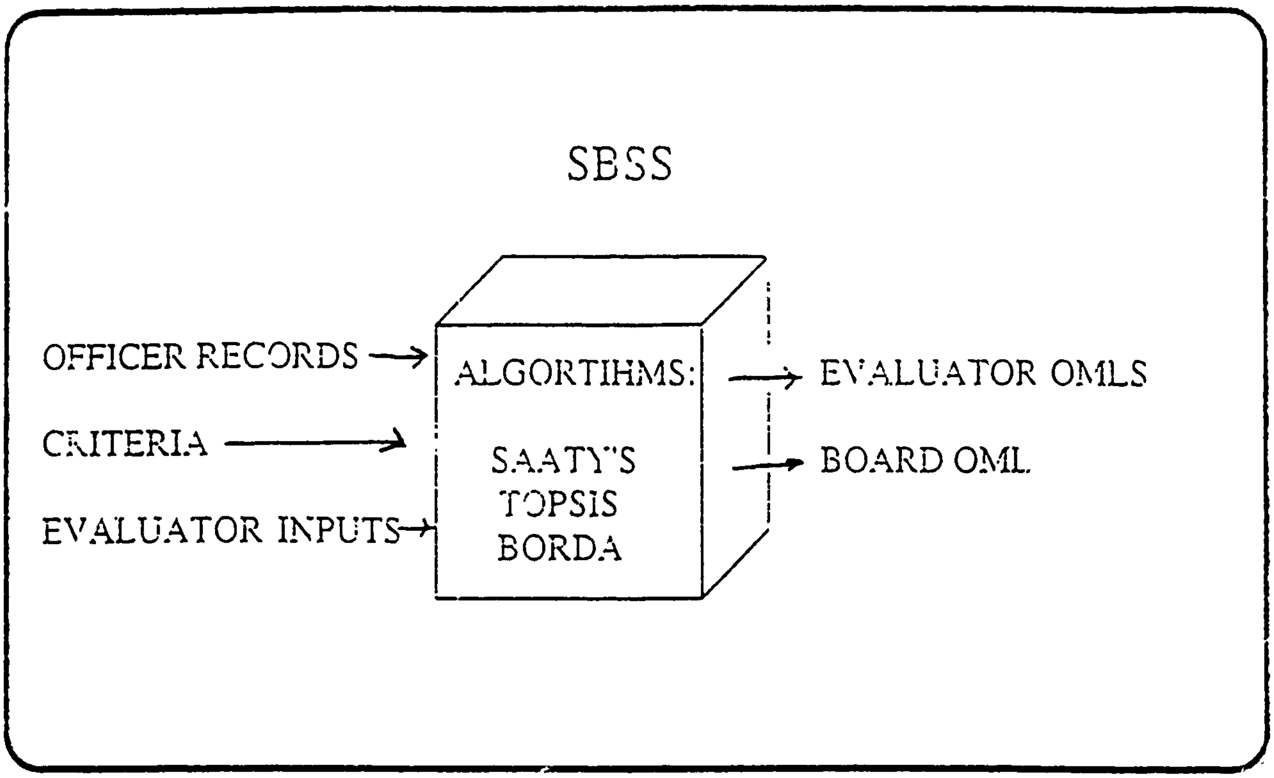

TABLE 2

	(Wts)	OFFICERS			
		1	2	3...m	
Physical Readiness/Military Bearing	(.10)	8	6	9	3
Military Education Level	(.05)	5	5	8	4
Civilian Education Level	(.20)	6	4	5	6
Assignment History	(.05)	7	6	7	5
Duty Performance	(.60)	7	4	8	3

TABLE 3

RESULTS

SIGN TEST

REJECT IF -1.96 > Z > +1.96

	IDEAL	SSAW	PCSAW	STOP	PCTOP
IDEAL		Z1 =.2443 Z2 = .3810 ACCEPT	Z1 = 0.0 Z2 = 0.0 ACCEPT	Z1 = .0155 Z2 = .3750 ACCEPT	Z1 = 0.0 Z2 = .4887 ACCEPT
SSAW			Z1 = 1.3245 Z2 = 0.0 ACCEPT	Z1 =.6934 Z2 = .9899 ACCEPT	Z1 = 1.3245 Z2 = 1.1078 ACCEPT
PCSAW				Z1 = 2.0421 Z2 = .3873 REJECT	Z1 = 0.0 Z2 = .4961 ACCEPT
STOP					Z1 = 2.0421 Z2 = .2641 REJECT
PCTOP					

TABLE 4

RESULTS

WILCOXON TEST REJECT IF -1.96 > Z > +1.96

	IDEAL	SSAW	PCSAW	STOP	PCTOP
IDEAL		Z1 = -.0062 Z2 = -.2980 ACCEPT	Z1 = -.1437 Z2 = -.1601 ACCEPT	Z1 = -.1054 Z2 = -.2441 ACCEPT	Z1 = -.1437 Z2 = -.1187 ACCEPT
SSAW			Z1 = -.6912 Z2 = -.2738 ACCEPT	Z1 = -.4189 Z2 = -.7288 ACCEPT	Z1 = -.6912 Z2 = -.3322 ACCEPT
PCSAW				Z1 = 0.0 Z2 = -.2172 ACCEPT	Z1 = -1.0476 Z2 = -.3790 ACCEPT
STOP					Z1 = -1.0476 Z2 = -.0953 ACCEPT
PCTOP					

TABLE 5

RESULTS

COMBINED CORRELATION MATRIX

	IDEAL	SSAW	PCSAW	STOP	PCTOP
IDEAL	1.000	.886	.917	.906	.915
SSAW	.886	1.000	.951	.988	.983
PCSAW	.917	.951	1.000	.976	.988
STOP	.906	.988	.976	1.000	.994
PCTOP	.915	.983	.988	.994	1.000

The Officer Promotion Plan (OPPLAN)
A Simulation in GPSS V

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Officer promotions have slowed in the last several years, particularly in the three field grades. The results are higher pin-on-points and promotion list backlogs. These conditions are caused by a number of factors some of which, taken singularly, are positive, but collectively have a negative impact on certain aspects of the promotion process. For example, the statutory requirement for officers promoted to Lieutenant Colonel and Colonel to serve three years time in grade prior to retirement, Congressional desire (not mandated by law) to have an all regular career force following promotion to Major, and improved retention rates since the Defense Officer Personnel Management Act (DOPMA) took effect are factors affecting field grade promotions today. Force reductions mandated by Congress have further irritated promotion flow since promotion policies have been slow in compensating for the adjusted force.

Army personnel managers have a limited number of measures for adjusting promotions. Congressional guidelines provide the framework within which these measures are applied. Any adjustments to the system require a thorough understanding of the impact on promotion trends. Changes in the promotion system framework, or shortsighted application of measures, sometimes result in undesirable promotion trends; the field grade promotion backlog being a case in point. There is a need for systemic analysis of the possible costs, benefits, and trends associated with proposed policy decisions arising out of system adjustments or changes to the system framework. The Officer Promotion Plan (OPPLAN) addressees this need by modeling promotions in the three field grades.

The officer promotion system consists of two complimentary processes: a selection process (input) and a promotion process (output). The first is that portion of the promotion system that determines when a promotion board is convened, determines who is eligible for appearing before the board, establishes guidelines for adjudicating individual files for selection, and sequences selectees in order of promotion. The second, the promotion process, controls grade inventories and is governed by legal statutes and budgetary considerations. The Defense Officer Personnel Management Act (DOPMA), Public Law 96-153, which took effect on 15 September 1981, and modernized the officer personnel management system, provides much of the guidance for the officer promotion process. Specifically, DOPMA contains guidance on the number of field grades allowed based on service end strength. These grade ceilings constrain the field grade inventories as the size of the Army fluctuates. The Act also addresses promotion opportunity - the percentage of an eligible population selected for promotion. The rates adopted when DOPMA took effect target promotion opportunities of 80% for Major, 70% for Lieutenant Colonel, and 50% for Colonels. Last, DOPMA provides a career progression template designating pin-on phase points between 9 and 11 years for Major, 15 to 17 years for Lieutenant Colonel, and between 21 and 23 years for Colonel.

The Army has established several management practices that are important components of the promotion system. First, boards convene annually, at different times in the year for each grade. Second, grouping officers commissioned during the same year into cohorts enables officers to compete with the same eligible population throughout their careers. Over time, the composition of year group cohorts slightly change as some officers are selected early for promotion and advance into another cohort or, visa versa when they are selected late for promotion. Year group cohorts help synchronize the promotion process with other personnel management processes, especially command and school selections. Last, in conjunction with annual selection boards, personnel managers expect to exhaust promotion lists in 12 months, so as not to have more than one list per grade "on the street" at a time.

As evidenced by the current backlog in field grade promotions, the Army must continually look ahead for problems caused by management practices as they are applied within the legal framework established by Congress. Inherent in this responsibility is the need to periodically review the framework's relevancy as well. Also, a tendency exists for managing the selection and promotion processes separately. This is somewhat unavoidable because managers lack analytical tools for relating the two processes. This lack of tools both diminishes our capability to anticipate problems that inherently arise from system changes as well as predict when changes are needed. Analytical tools provide personnel managers a more educated, informed perspective of the system from which to make decisions.

As in any modeling effort, assumptions are made to bridge the gap between reality and what can practically be represented in the model. OPPLAN assumes that current management practices, as outlined above, will continue and that Congress will not change the promotion system framework, as spelled out in current law, in the near future. Most importantly, OPPLAN necessarily assumes that promotions will be strictly governed by DOPMA ceilings (spaces) and the budget (dollars). In real-world promotion management, flexibility exists from month to month in the space and dollar ceilings. In practice, the DOPMA ceilings for field grade officers and the budget (in terms of commitments made) can be exceeded monthly to the degree that the system can be managed back to within those constraints by the last day of the fiscal year. GPSS V needs an interactive programming capability, which it does not have, to properly model the decision process that allows flexibility in real-world management. Hence, the model assumes that monthly ceilings are absolute at all times.

To meet the goal of making informed and timely promotion decisions, the model is designed as an iterative program that views the relationships between changes in the input variables and the system output variables. In this case, the number promoted, how quickly promotion lists get exhausted, and the career timing of promotions are the outputs used to measure system effectiveness. By varying values of the input variables i.e., grade ceilings, selection rates, forced losses, and budget, trends in the output variables are observed and analyzed. Similarly, if a particular outcome is desired, such as exhausting promotion lists in a specific time, the cost of achieving this trend, in terms of the remaining independent and dependent variables, is determined. One other model variable, the grade attrition rates, are the product of a related modeling effort. These rates are applied against the grade inventories, creating all the system vacancies except those that occur through promotion to the next higher grade. Historical loss data is used and a (monthly) probability of continuation distribution for each grade is built. Since actual continuation rates reflect the "present" state of the promotion system and the modeled rates are derived from historical data, the validity of the distributions must continually be evaluated in view of current system trends and the fact that they are being used to predict future trends.

The assumptions and variable relationships lead to an algorithm describing the necessary conditions for promoting an individual to the next higher grade. A promotion occurs if sufficient uncommitted budget remains to fund an individual in the next higher grade for the remaining portion of the fiscal year he/she will serve in the next higher grade and if the current inventory in the next higher grade is under the grade ceiling established by law. The algorithm is expressed as follows:

$$\text{BUDGET} + \text{SPACE} = \text{PROMOTION} \tag{1}$$

Thus, a promotion must be vacancy supported and budget supported to occur. However, as noted earlier, at times promotion managers gain some flexibility by making only one condition sufficient for promotion (as long as the system can be managed back to within the limits by the end of the fiscal year).

The Officer Promotion (OPPLAN) model algorithm is not as flexible. Equation (2) expresses the variable relationships involved in describing a budget supported promotion.

$$\overset{\text{BDGT}}{\text{REM}}(t) - \overset{\text{CUR}}{\text{INV}}(t) - \left[\overset{\text{CUR}}{\text{INV}}(t) - (\text{LOSSES}(t) + \text{PROM}(t))(12 - T) \right] = \begin{matrix} + \text{ UNDER} \\ 0 \\ - \text{ OVER} \end{matrix} \qquad (2)$$

The two terms outside the large brackets express the total remaining budget available for spending on a grade's inventory at any time (t) (where t is any month). The terms inside the brackets describe that portion of the remaining budget committed to the end of the fiscal year. Therefore, the difference between the remaining budget and the committed budget, i.e. the right hand side, is a measure of spending discipline. For example, if the left-hand side equals zero, spending is on target. A positive number on the right-hand side indicates under spending, and thus the potential for more promotions. Similarly, vacancy supported promotions are described by Equation (3).

$$\begin{matrix}\text{GRADE} \\ \text{CEILING}\end{matrix} - \left[\overset{\text{CUR}}{\text{INV}}(t) - \text{LOSSES}(t) + \text{PROM}(t) \right] = \begin{matrix} + \text{ UNDER} \\ 0 \\ - \text{ OVER} \end{matrix} \qquad (3)$$

The difference between the grade ceiling (or available spaces) and the remaining terms (or the spaces filled at time t) measures the level of fill for a particular grade. Setting the right-hand sides equal to zero and solving Equations (2) and (3) for PROM(t), yields expressions for calculating the number of promotions that can be made at time (t), in terms of budget and spaces respectively. Comparing the two numbers and selecting the smaller provides the maximum number of promotions allowable without violating either constraint.

The OPPLAN model is programmed in modules around this central algorithm. The system is modeled as a queue. There are no servers modeled with service time distributions. Instead the algorithm provides the conditions allowing "servicing" of the queue - acting as a gate that controls the number of transactions promoted (i.e., "serviced") each time step. A transaction represents an individual selected for promotion and awaiting conditions for pin-on (slack in the constraints). The selection process is not part of the model and requires an off-line calculation to estimate promotion list sizes.

The first module, the queuing module, organizes transactions into these predetermined lists (queues) and sequences the lists. Sequencing is accomplished by giving transactions attributes particular to their grade and priority.

Since current grade backlogs are characterized by as many as three lists waiting for promotion, the queuing module recreates the state of the system using a snapshot in time, normally chosen as the start of the most recent fiscal year.

The second module performs the simulation bookkeeping and maintains the statistics used for analysis. The model begins promoting transactions based on quotas initialized for the first time step. Transactions move through a series of conditional logic gates which either check it for a particular attribute or check it against a quota count. For example, a transaction may be checked for a grade attribute of "4", meaning O4/Major, and checked against the monthly promotion quota to determine if promoting the transaction would exceed the capability for that time step. Also, a clock is maintained on transactions waiting in the promotion queue. The clock determines overall list durations. As transactions move through the bookkeeping module, they are counted. This allows updating of the system counters (e.g. monthly quotas, list lengths, clock time, DOPMA spaces, and grade inventories) and adjusting the budget. The bookkeeping module is the largest module, involving over fifty logic gates that model the administrative actions that occur from the time an individual gets placed on a promotion list through promotion.

The series of logic gates and counters in the bookkeeping module recognizes the last transaction promoted each month. This transaction is the only transaction that enters the final module, the system effects module, triggering the calculations for the next month's promotion quota. Here, factors affecting the promotion process are modeled and combined with the basic system algorithm calculations producing the monthly quota. Some of the factors affecting promotion vacancies are continuation rates, promotions to the next higher grade, and forced losses. The system effects module also advances all transactions still awaiting promotion to the next time step and, in turn, links the flow of transactions back into the bookkeeping module.

The simulation yields many statistics, some produced automatically by GPSS V and others developed through programming. Figure 1 depicts a portion of output from a hypothetical simulation run of Colonels.

The header statistics given in the output tells that year group (list) 1969 is being promoted, that 700 individuals were selected, the selection board convened in fiscal year FY90, and that the number of months (simulation time steps) it takes to promote the entire list is 13 months. Additionally, the output header says that these statistics occur based on a modeled 40.6% selection rate and the forcing out of 175 officers (for example, through selective early retirements).

YR GRP	# ON LIST	FY	LIST DURATION (MONTHS)	% SELECTED	FORCED LOSSES
69	700	90	13	40.6	175

MONTH	MONTHLY PROMO CAP	BUDGET CAP	DOPMA CAP	MONTHLY LOSSES	CURRENT INVENTORY	PIN ON
1	50	50	120	40	2837	22.1
2	50	50	90	52	2835	22.2
3	60	60	70	43	2842	22.3
4	70	70	80	26	2876	22.4
5	50	50	100	41	2905	22.5
6	30	60	30	41	2914	22.6
7	30	70	30	30	2914	22.7
8	20	50	30	30	2914	22.8

Sample Output

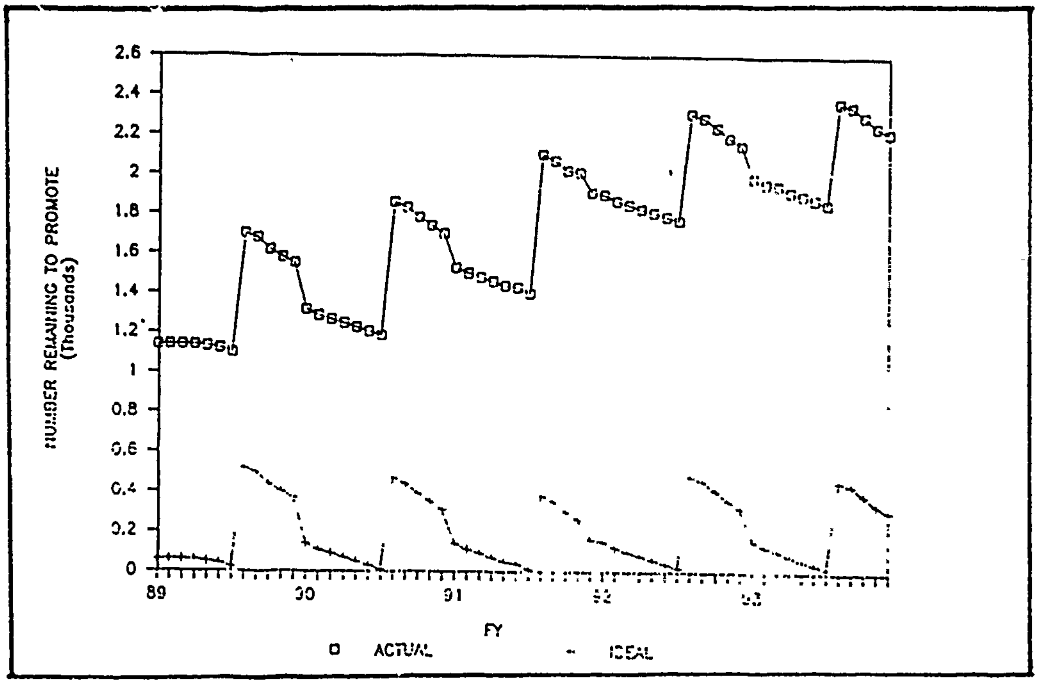
FIGURE 1

The data listed underneath the header statistics provides a monthly promotion projection. The "MONTH" field lists the months of the fiscal year, with October being number one. The second field shows how many promotions the simulation allows each month. The data in this field compared to the data in the next two fields, the BUDGET and DOPMA capabilities, indicates which of the two resources constrained promotions each month. The "MONTHLY LOSSES" field records the inventory losses calculated by the attrition distributions mentioned previously. These are natural losses unrelated to the forced losses shown in the header statistics. The "CURRENT INVENTORY" field keeps a running balance of the grade inventory at the end of each month, accounting for the increases due to promotions and the various losses. Data shown in the "PIN ON" field tracks the wait for promotion in terms of total years of service. For example, the last entry value of 22.8 means that the 20 people promoted in the eight month (May) pinned on their rank at 22 years and 8 months of service. The simulation calculates these values from a baseline representing the average time in service an individual has at selection board adjournment. This average is taken from historical promotion board statistics.

As noted previously, some analysis results are obtained from a glance at the output. Other analyses require data manipulation and graphical display for obtaining results. The strength of OPPLAN lies in its capability of viewing changes to a single policy or factor, multiple policies or factors simultaneously, or incremental adjustments through iteration. Additionally, changes are viewed over time (with the default being five years) in order to produce trends for analysis.

Colonel Promotion Backlog-Base Case

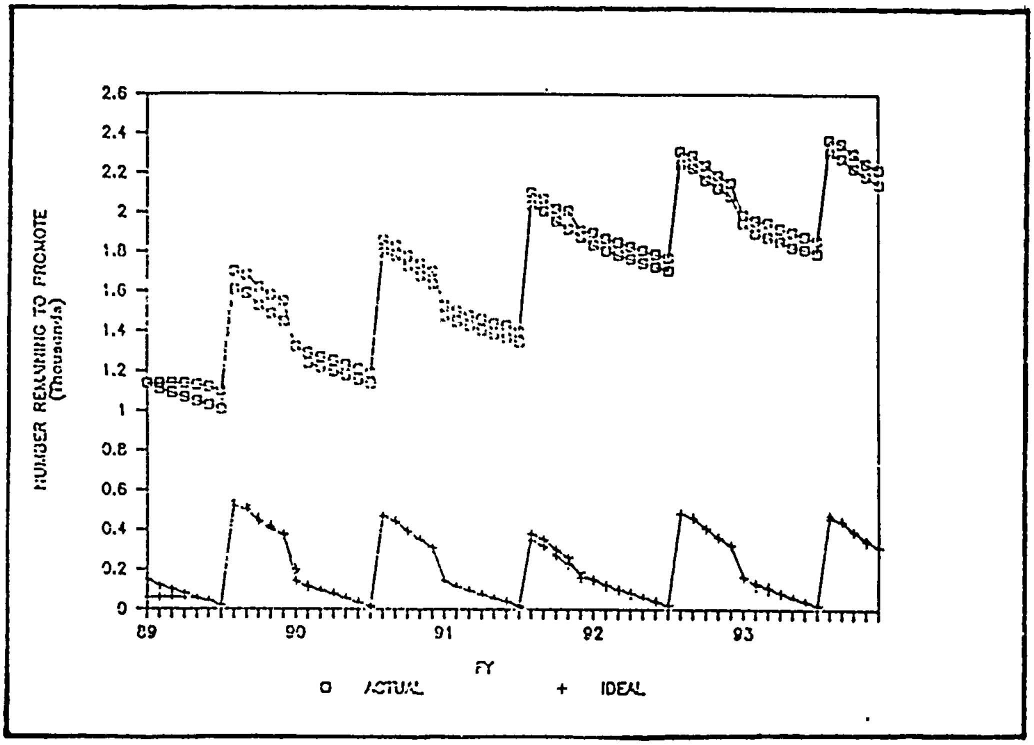
FIGURE 2



The following scenario demonstrates part of an OPPLAN analysis conducted. The results for the grade of Colonel illustrate many of the simulation's capabilities. Promotions to Colonel are taking about two years from the list release date and up to three lists are backlogged. The graphs in Figure 2 depict the current promotion trend (top) against an ideal trend (bottom). The ideal graph means that a promotion list is completed a year from its list release date, that only one list at a time is in the queue and that monthly promotions never exceed capability. The bottom graph depicts promotion capability constrained by projected budget levels and the law. The vertical jumps coincide with new list release dates and depict ideal list sizes (annual promotion capability). Similarly, promotions in the top graph are constrained by budget and law but list durations are not held to one year. Selection rate, which determines the height of the vertical jumps in the top graph, models current guidance. Note that the Y-axis measures the number of people waiting for promotion and that the top graph's position relative to the Y-axis scale indicates that promotions are backlogged. Figure 2 represents the "base case" or, in other words, what trend is expected if current practices continue unchanged. A visual analysis shows that the current selection rate for Colonel is too high to reduce the backlog trend of promotable Lieutenant Colonels over the next five years. Two areas indicate this. First, the slope of the top graph relative to the bottom, or ideal, is increasing and thus the number remaining to promote is growing. Second, the projected list sizes, as depicted by the vertical jumps in the top graph, are consistently larger than those on the ideal graph indicating that projected selections exceed our capability to promote each year.

Colonel Promotion Backlog-Increased Finding

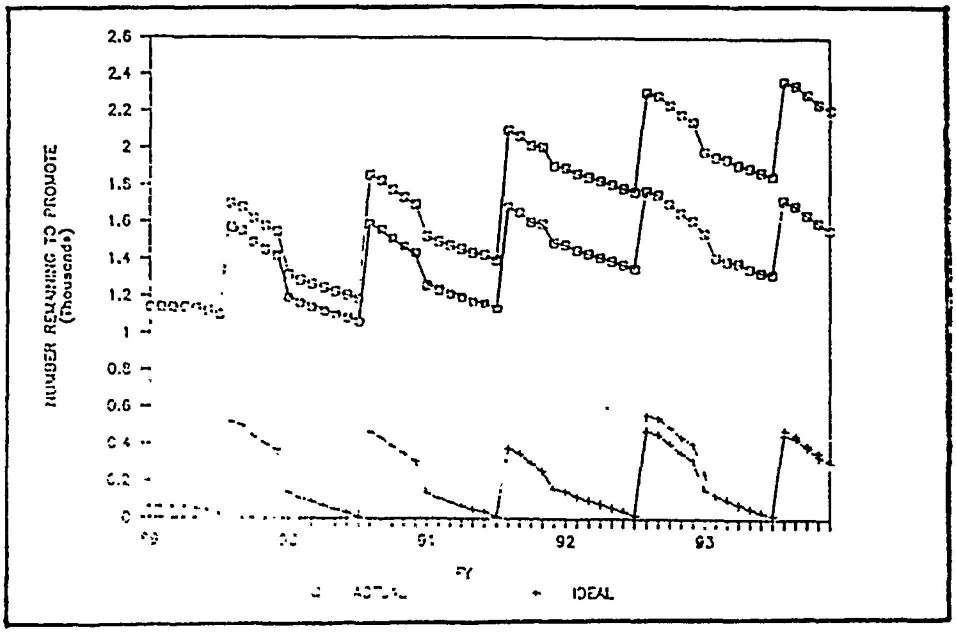
FIGURE 3



Reducing the promotion backlog requires changing one or more factors effecting the promotion rate for Colonels. For example, if we determine from the data that monthly promotions are not constrained by the DOPMA ceiling but instead, by the available dollars, increasing the Colonels budget should increase the rate of promotions. To the extent this is successful, we should observe the slope of the top graph become less positive (i.e., the number of people waiting to be promoted get smaller). Figure 3 depicts the results of increasing the Colonels FY89-FY94 budget. Comparing the two upper graphs shows that the increased budget does little to reduce the promotion backlog. While the effect in FY89 is to promote people faster, the corresponding decrease in promotion backlog, as seen by the gap between the two top curves, is minimal and unimproving from FY90 on. The reason is that the increased FY89 promotions have taken the Colonel inventory to its legal limit i.e., Colonel promotions are now constrained by DOPMA instead of budget. As a potential solution for reducing the backlog, increasing the Colonel budget in order to promote more to that grade, is not sufficient.

Colonel Promotion Backlog-Lower Selection Rate

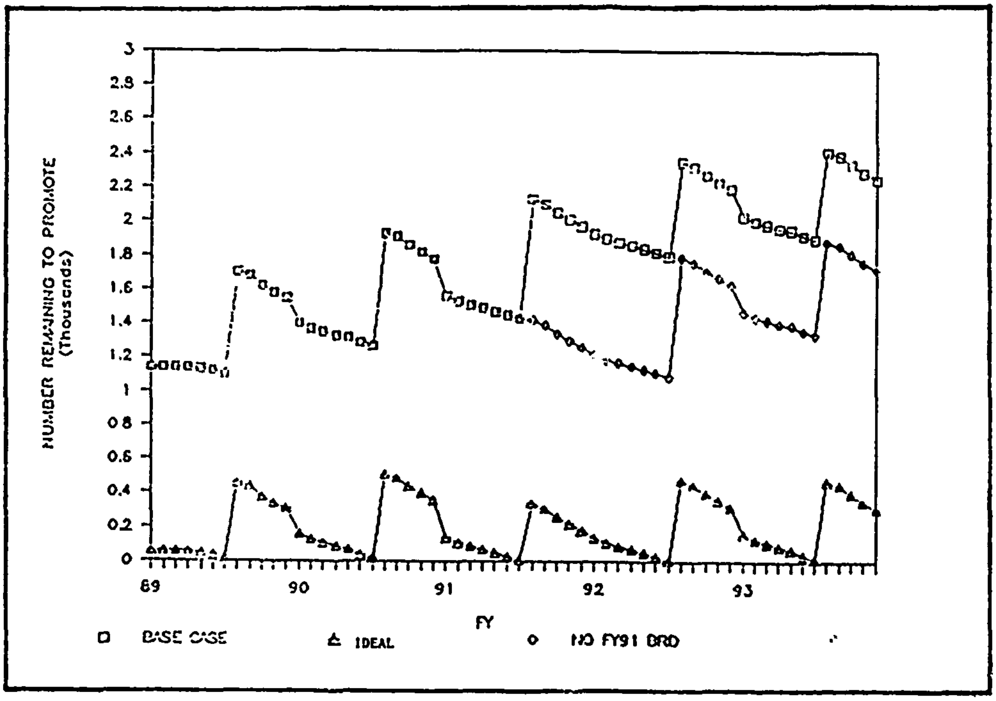
FIGURE 4



Two more examples illustrate alternative analyses for exploring solutions to the Colonel promotion backlog. The graph in Figure 4 contrasts the current promotion trend with the trend if selection rate is reduced. Again, compare each of the upper curves with the ideal, or lower curve. Reducing the selection rate (promotion opportunity) by 16 % substantially decreases the promotion backlog. While the overall improvement is obvious, the backlog remains and actually continues growing slightly despite the lower selection rate. The reason is evident from comparing the vertical jumps representing promotion list sizes. Even with the reduction in selection rate, the projected list sizes exceed the ideal list sizes. If we continue decrementing the selection rate and running OPPLAN iteratively, the value of the selection rate causing the upper curve to turn towards the lower curve can be determined (not shown). Using this value and running the simulation out past FY94 determines the point where the two curves merge. The dependent and independent variable values causing the merger then define a plan (an alternative) for correcting the Colonel backlog. Figure 5 depicts another approach. In this example, no selection board is held in FY91, the idea being to continue promoting the backlog without adding more individuals to the queue. Note that between May 1992 (when a new selection list is usually released into the queue) and May 1993, the number remaining to promote drops significantly when no board is held. Subsequent boards however, select at the usual rate which, as implied by the previous example, is too high. From May 1993 on the backlog continues to increase because of the selection rate.

Colonel Promotion Backlog-No Fy91 Board

FIGURE 5



While some of the conclusions from the previous examples may be intuitive, the simulation data provides a way to verify intuition, measure results, and observe simultaneous effects on the three field grades. The simple examples shown in Figures 3 through 5 indicate that a lower selection rate is important to any solution to the Colonel backlog. But a final promotion plan has to consider the collective effects on all three grades, not just Colonels as given here. And it should consider other aspects of the promotion system such as list lengths and pin-on-points. As such, any final plan is more than likely based on compromises between competing factors. In the example where selection rate is reduced, not only does the 16% reduction take the Colonel select rate far below the DOPMA objective, but it results in only small decreases in the Lieutenant Colonel and Major backlogs. Further excursions exploring changes across the entire range of factors, the central feature of which may be reduced selection rates, are necessary. A complete analysis using OPPLAN considers the trade-offs between promotion points, budget, list durations, forced losses, and selection rates. These trade-offs are viewed from feasibility, affordability, and supportability (i.e., if inventory meets authorizations) perspectives.

The simulation can be improved upon in several areas. As pointed out earlier, GPSS V does not have an interactive capability, making iterations a cumbersome process. While the model runs quickly, reinitializing the inputs to test various scenarios is time consuming. Since GPSS V was the only simulation language resident on the mainframe, there were few alternatives to using it (FORTRAN was considered). The time and cost of obtaining another language with an interactive capability made using GPSS V necessary. Also, the number of active transactions the simulation handles is limited to 1200 which is significantly less than the total number of promotable officers in the system at any one time. This required the program structure to process the grades in "series" versus assigning each transaction a priority attribute and allowing processing in "parallel", time step by time step. That is, all Colonels are processed first and Majors last. All the model generated data associated with Colonels, for each time step, is stored in a matrix, creating snapshots in time of the Colonel promotion process. Start time is reset for Lieutenant Colonels and the Colonel matrix is accessed for the corresponding snapshot of data at each Lieutenant Colonel time step. The procedure is similar for Majors. The large arrays required for storing the data further limit the program by reducing the number of code lines ("blocks" in GPSS terms) the language can keep track of. While this latter fact is manageable (it does not leave a lot of memory for formatting output), the 1200 transaction limitation forces "a transaction" to represent a group of promotable officers (up to ten) for those grades whose promotion queue exceeds 1200 individuals. Again, it makes the program cumbersome by forcing conversion of the output data into one-for-one data.

To date the Officer Promotion Plan has provided supporting analysis in developing the Deputy Chief of Staff For Personnel (DCSPER) Five Year Promotion Plan. The Officer Division of the DCSPER's Military Personnel Directorate plans on incorporating OPPLAN analysis into the Strategic Personnel Management Plan being developed for the Army Chief of Staff during FY89-FY90.

E5/E6 TARGET GENERATION STUDY

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1. BACKGROUND

a. Promotions into the enlisted grades E5 and E6 are determined every month from a semicentralized analytical system by individual military occupational specialty (MOS). The Office of the Deputy Chief of Staff for Personnel (ODCSPER) provides policy direction for the system and the United States Total Army Personnel Agency (TAPA) operates the system to determine the actual monthly promotions. Crucial input, in the form of projected adjusted authorizations for each MOS and grade, is provided by General Research Corporation (GRC) through the Military Occupational Specialty Level System (MOSLS) on FORECAST, the Headquarters, Department of the Army, Decision Support System.

b. Throughout this study, different personnel strengths are discussed. Authorizations or authorized strength can be thought of as the number of soldiers the Army has decided to fill in each MOS and grade. Authorizations are derived from the Personnel Authorizations Module (PAM) which is updated monthly. For planning purposes, authorizations are projected over the next 7 fiscal years. These projections are used for determining promotions as well as planning training requirements. These authorization projections tend to fluctuate over time as a result of equipment changes and activation and deactivation of units. Operating strength is the number of soldiers the Army has assigned to different units, not including trainees, transients, holdees, and students (TTHS).

c. The fundamental criterion for evaluating the effectiveness of the E5/E6 promotion system is based on the measurement of operating fill. Operating fill is the ratio of operating strength to authorized strength. Operating fill at or near 100 percent in each MOS over successive months is indicative of an effective system. The process of maintaining operating fill has two distinct components. The first component is the process which generates targets, which are adjustments made to the projected authorizations to better meet manpower requirements over time. Targets are adjusted projected authorizations. There are three major reasons for using targets in lieu of raw authorizations. The use of operating strength targets provides a capability to (1) correct known errors in the authorization data base, (2) account for undocumented personnel requirements, and (3) provide for manning ramps with the appropriate lead time or lag time when authorizations are increasing or decreasing. The second component is moving operating strengths to the targets or target strength. This can be done through reclassifications, accessions of prior service personnel, reenlistments, and promotions. This study focuses on promotions, since this is the primary method of adjusting the operating strength.

2. **THE PROBLEM.** A study to evaluate the effectiveness of the target generation process with respect to maintaining operating fill--over all MOS, in grades E5 and E6, and over time--has not previously been performed. Nor has the potential of developing an optimal target generation process been fully explored. This study focuses on the relationships between authorizations, targets, and the resulting operating strengths to satisfy the Army's goal of investigating how the Army can improve the process of moving operating strength to authorized strength.

3. **STUDY OBJECTIVES**

a. Evaluate the effectiveness of the current target generation process based on the measurement of fill (operating strength relative to authorized strength) of enlisted grades E5 and E6 over all MOS and over time.

b. Develop and evaluate alternate methods of target generation based on the measurement of fill (operating strength relative to authorized strength) of enlisted grades E5 and E6 over all MOS and time.

4. **THE STUDY SCOPE.** The objectives are evaluated on the basis of the study scope specified as follows.

a. This study is limited to examination of analytical modifications pertaining to the target generation process of the current E5/E6 promotion system.

b. Examination of the current and modified E5/E6 promotion system is based on 12 consecutive simulations of the system for the 12 most recent months of historical authorizations and targets (February 1987-January 1988) for all MOS in grades E5 and E6 common to the 12 months of analysis (265 MOS, grade E5, and 242 MOS, grade E6).

c. Evaluations of the current system and modifications to the current system are based on fill (operating strength relative to authorized strength). Different variations in the measurements of fill which are applied to this study are:

- Numbers of MOS in different categories of fill.

- Strength in different categories of fill.

- Magnitude of understrength (the number of soldiers who are needed to fill MOS, over all MOS for which operating strength is less than target strength).

- Magnitude of overstrength (the number of soldiers who exceed target strength, over all MOS for which operating strength is greater than target strength).

d. Categories of fill (as defined by the Army Enlisted Personnel Management Plan (EPMP), FY 1987 - FY 1991) which will be applied to this study are:

- Number of critically imbalanced MOS, underfill:
  fill < = .80
- Number of moderately imbalanced MOS, underfill:
  .80 < fill < = .95
- Number of balanced MOS:
  .95 < fill < = 1.05
- Number of moderately imbalanced MOS, overfill:
  1.05 < fill < = 1.20
- Number of critically imbalanced MOS, overfill:
  fill > 1.20

5. LIMITATIONS

a. Limited availability of historical authorizations and targets makes reproduction of the E5/E6 promotion system possible for only 12 months of consecutive analysis.

b. Evaluation of alternate target generation processes is based on simulation of the E5/E6 promotion system. In that unique complexities are characteristic of this system, generalization of findings to other manning systems may not be possible.

6. TIMEFRAME. February 1987 - January 1988.

7. KEY ASSUMPTION. Simulation of the E5/E6 promotion system based on 12 months of the most recent available data within FY 1987-1988 will be sufficient for evaluative purposes.

8. THE APPROACH/METHODOLOGY. Study methodology consists of (a) development of alternate target generation processes, (b) simulation of the E5/E6 promotion system as affected by alternate target generation processes, and (c) evaluating performance of the E5/E6 promotion system based on measures of operating fill.

a. Alternate Target Generation Processes. In order that operating strength can more realistically follow abrupt fluctuations which occur in the projected authorizations, it is customary to "smooth" the authorizations using statistical smoothing techniques. Thus, the original focus of the study was on these abrupt fluctuations and on the most effective application of statistical smoothing techniques to smooth the fluctuations. The smoothing of authorizations occurs at the third stage of a six-stage computational process used to generate targets. The six-stage process is shown as path 1 of Figure 1 and is described below. Emerging results indicated, however, that evaluation of variations of the six-stage computational process, rather than different statistical smoothing techniques, would lead to results having more impact on fill. Consequently, target generation processes were conceptualized as five different paths, as illustrated in Figure 1.

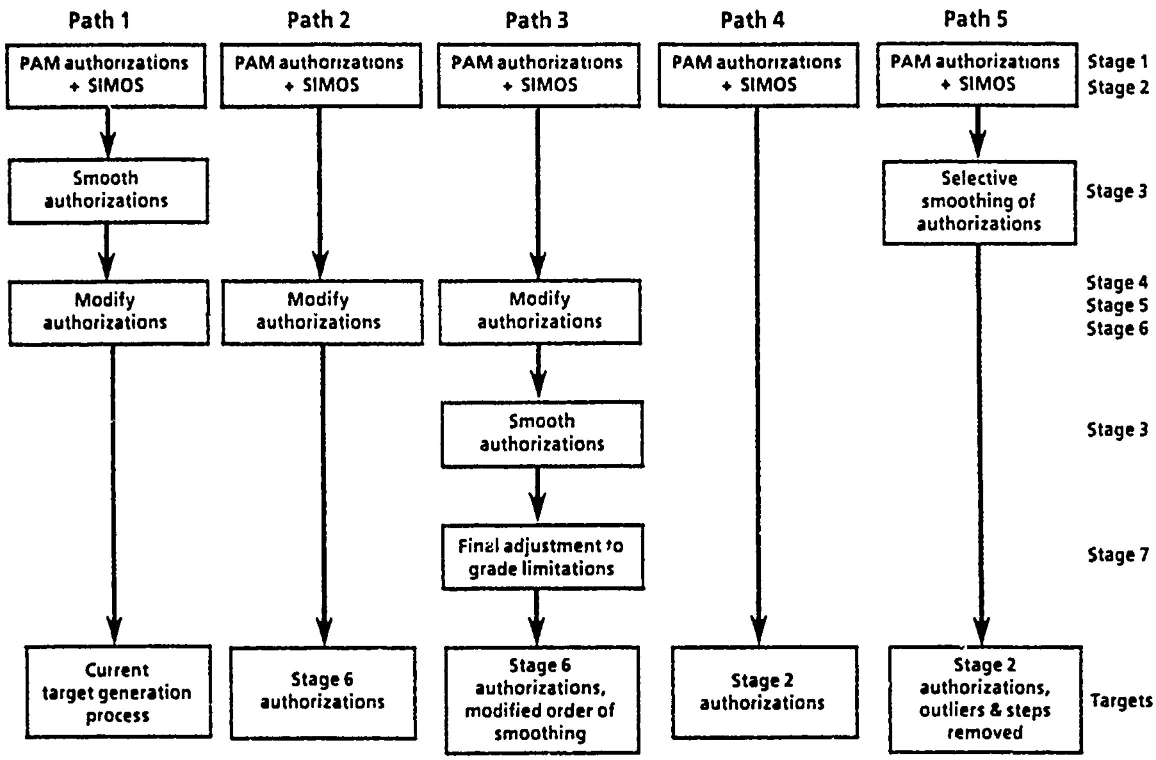

Figure 1. Target Generation Process

(1) Path 1 (current target generation process). Path 1 of Figure 1 represents the current target generation process which consists of six computational stages:

(a) The source of the stage 1 authorizations is the Personnel Authorizations Module of the FORECAST/MOSLS system.

(b) Authorizations can be inflated in stage 2 to account for undocumented personnel requirements.

(c) Smoothing authorizations occurs in stage 3. Examples of statistical smoothing techniques included in this study are (1) weighted moving average, (2) Tukey-Riffenberg method, (3) exponential smoothing, (4) removal of outliers method, and (5) ramp method. A description of the statistical smoothing techniques can be found in Chapter 3.

(d) Authorizations are additionally adjusted to meet Armywide strength projections, to incorporate trainees, holdees, and students, and, finally, to meet constraints by grade (stages 4, 5, and 6).

(2) Path 2 (stage 6 authorizations). Path 2 is a reproduction of the current target generation process, but with the smoothing eliminated.

(3) **Path 3 (stage 6 authorizations, modified order of smoothing).** In path 3, the smoothing of authorizations is moved to occur subsequent to stages 4, 5, and 6.

(4) **Path 4 (stage 2 authorizations).** In path 4, the stage 2 authorization is directly used as the target.

(5) **Path 5 (stage 2 authorizations with outliers and steps removed).** Path 5 refers to the selective smoothing of stage 2 authorizations which fluctuate as outliers or which take the shape of steps.

b. **Simulation of the E5/E6 Promotion System.** Evaluation of alternate target generation processes based on simulation of the E5/E6 promotion system is illustrated in Figure 2. Targets are used to determine numbers needed for promotion. When operating strength is less than target strength, vacancies occur, and the Army promotes to fill vacancies. The accumulated effect on operating strength which occurs as the result of promotions derived from different targets--for all MOS in grades E5 and E6 and over 12 successive months--is the product of the simulation.

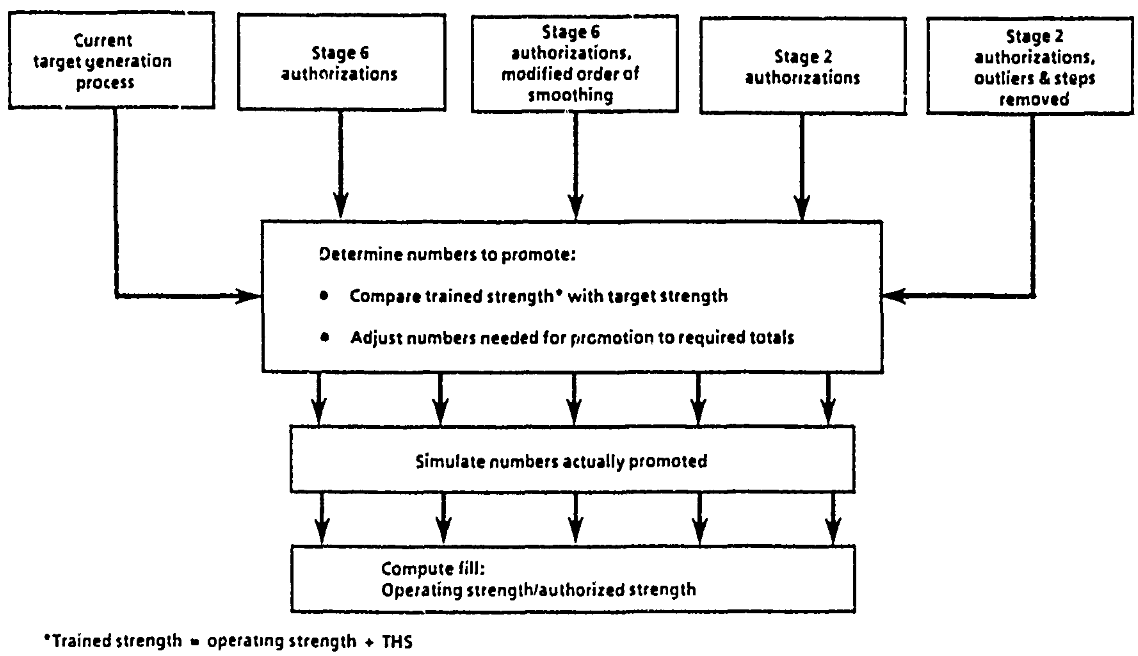

Figure 2. Comparing Target Generation Processes

c. **Complexities.** In addition to the effect of the target, a number of complexities exist within the E5/E6 promotion system which affect operating fill. The five most significant complexities are described below.

(1) **Projections.** Promotions are determined for 1 month in the future. About 2 months are required to develop records of actual operating strength. Consequently, the time span between the most recent available records and the month for which promotions are needed covers 3 months; that is, promotions are based on projections 3 months ahead.

(2) **Constraints on Numbers Needed.** A ceiling on total numbers of promotions into grades E5 and E6 is provided every month. Consequently, numbers needed, as determined by the difference between projected operating strength and the target, are constrained to meet the required sum. (The constrained numbers needed are referred to as "promotion determinations.")

(3) **Differences Between Promotion Determinations and Actual Numbers Promoted.** The promotion determination is used to derive a "cutoff score" for every MOS in grades E5 and E6. Soldiers eligible for promotion into grades E5 and E6 who have cumulations of promotion points which are equal to or exceed the cutoff score are automatically promoted. Ideally, actual numbers promoted should equal the promotion determinations, but differences do occur.

(4) **Insufficient Eligible Soldiers and Overfill.** Too few soldiers eligible for promotion or prior existence of overfill may obscure the effect of any given target.

(5) **Changing Authorizations Documents.** Effectiveness of the E5/E6 promotion system is based on reports of operating strength relative to authorized strength produced monthly by ODCSPER. Changes in authorizations documents, however, occur every month. Consequently, the authorization which drives the generation of the target and the determination of numbers needed for promotion may not be the authorization upon which the report of operating fill is based.

d. **Simulation of These Complexities.** To partially reduce complexities which confound the relationship between the target and operating fill, complexities (1) and (5) above were not included in the simulation of the E5/E6 promotion system. Complexities (2), (3), and (4) above, which represent distinct characteristics of the E5/E6 promotion system, however, were incorporated into the simulation. Study findings may be expected to be valid for the E5/E6 promotion system, but may not be generalized to other manning systems.

e. Evaluation Based on Fill. Evaluation of target generation processes is based on multiple measures of fill. Ideally, an improved process will have (1) increased numbers/percentages/strength of MOS categorized as balanced, (2) decreased numbers/percentages/strength of MOS in categories of underfill or overfill, and (3) decreased numbers of shortages and overages. Realistically, a process which improves balance may shift remaining imbalance from underfill to overfill (or vice versa). In evaluating the effects of the different processes, an effort is made to describe how the processes change the distribution of results with respect to balance/imbalance and shortages/overages. A process which improves balance but still accentuates underfill may be acceptable in one manpower environment, whereas a process which improves balance but accentuates overfill may be acceptable in another.

9. ESSENTIAL ELEMENTS OF ANALYSIS (EEA). The structure of this study focused on the questions asked in the essential elements of analysis (EEA) listed below. In this paragraph and in the following chapters, EEA 5 (as originally stated in the study directive in Appendix B) is presented after EEA 6 to provide an overall summary of results. Throughout this paragraph references are made to the alternate target generation processes described earlier in Figure 1. The current target generation process shown in path 1 has two versions of current targets, "historical" and "current." "Historical" targets are recreated by reading from actual records used from February 1987 through January 1988. In the first 7 of these 12 months, a double exponential smoothing technique was originally used to produce these targets; in the second 5 months (September through January), a weighted moving average technique was used. "Current" targets refer to a recomputation to produce targets for all 12 months using the current weighted moving average technique.

a. EEA 1: How do current targets compare with authorizations, based on measures of fill?

RESPONSE

(1) Figure 3 shows a comparison of current targets with authorizations for grade E5. As shown, stage 2 authorizations and stage 6 authorizations are both superior to current and historical targets in terms of percentages of balanced MOS. The greater superiority (by 6 percent balanced MOS), however, occurs for the stage 2 authorization, relative to the current method.

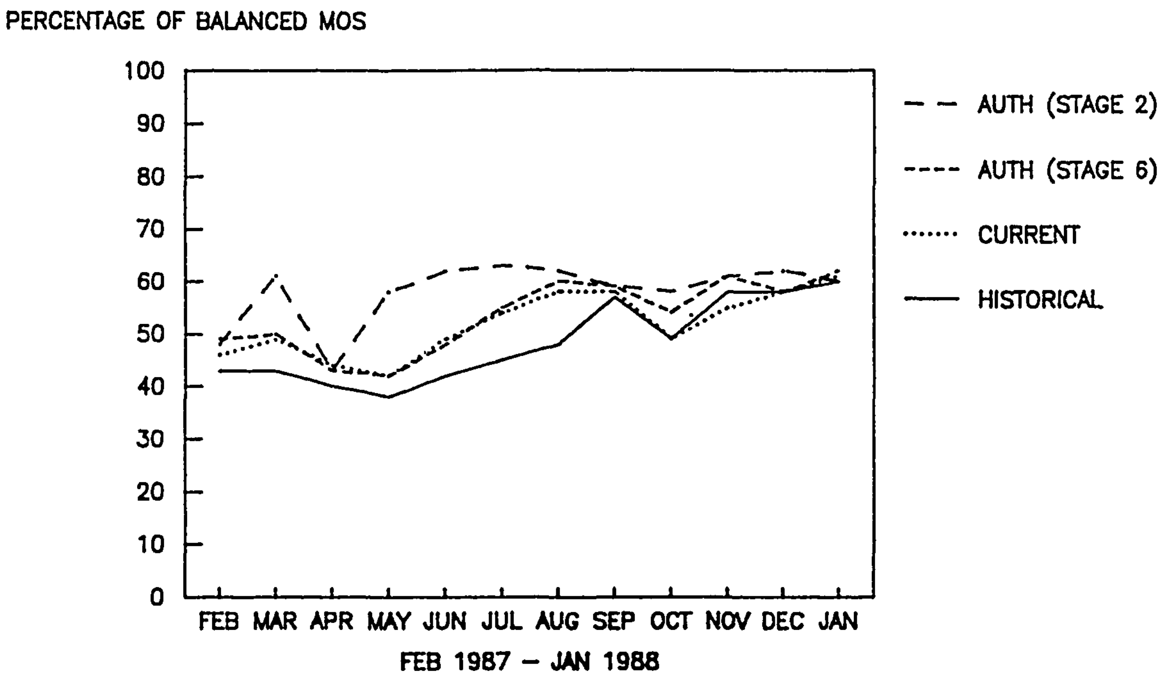

Figure 3. Comparing Current Targets with Authorizations, Grade E5

(2) Current targets are shown to be distinctly better than historical targets. Thus, the implementation of the current method was demonstrated to be a good decision.

b. EEA 2: What are the characteristics of those authorization patterns that produce large differences between operating strength, targets, and authorizations?

RESPONSE. While looking at projected authorizations, different characteristics of patterns were identified and categorized by outliers, sharp increases/decreases (steps), seasonality, ascending/descending authorizations, turbulence, changes in new authorization documents, as well as the authorization size of the MOS. Only some of these authorization patterns examined showed differences between operating strength and targets evaluated based on the percentage of fill. The authorization size showed that the smaller the size of the MOS, the smaller the percentage of balanced MOS occurred. Highly turbulent MOS within an authorization document and updating the new authorization documents also showed a low percentage of balanced MOS.

c. EEA 3: **What is the most effective method of generating targets for each pattern?**

RESPONSE. In determining the most effective method of generating targets, different statistical smoothing techniques were developed. These techniques included a weighted moving average, an exponential smoothing technique, the Tukey-Riffenberg technique, the removal of outliers techniques, the ramp technique, and the Tukey and outlier techniques combined. When these techniques were applied to the different patterns, no one technique was found superior relative to the current technique. Some patterns, however, showed a large increase in percentage of balanced MOS between the "historical" and the "current" technique which demonstrated that implementing the current technique was a good decision.

d. EEA 4: **If smoothing of the authorizations is appropriate, when in the target generation process should it be performed?**

RESPONSE

(1) Table 1 compares different statistical smoothing techniques smoothed at stage 2 and at stage 6 for grade E5. As shown, smoothing of authorizations should be applied to stage 6 authorizations rather than to stage 2 authorizations, when smoothing is by straight line removal of outliers ("Auth(stage 6)-outliers(SL)") or by the Tukey-Riffenberg statistical technique ("Auth(stage 6), T").

Table 1. Smoothing Order Comparisons, Percentage of MOS in Categories of Fill (8702-8801), Grade E5

Target process	Category of fill					
	Critically under	Moderately under	Balanced	Moderately over	Critically over	Total
Auth (stage 2), C	4	20	52	14	11	100
Auth (stage 6), C	4	20	52	14	11	100
Auth (stage 2), T	4	19	53	14	11	100
Auth (stage 6), T	4	19	54	13	11	100
Auth (stage 2) – outliers (SL)	4	19	53	14	11	100
Auth (stage 6) – outliers (SL)	4	17	55	13	10	100
Auth (stage 2) – outliers (MA)	4	18	53	14	11	100
Auth (stage 6) – outliers (MA)	4	19	52	14	11	100
Auth (stage 6)	4	19	53	13	11	100

C = Current smoothing technique; T = Tukey statistical smoother; SL = straight line method of removal of outliers; MA = moving average method of removal of outliers.

(2) The greatest improvement with respect to distribution of MOS in categories of fill occurs when straight line smoothing of outliers is applied to stage 6, rather than to stage 2 authorizations (percentage of balanced MOS increased by 2 percent and percentages of MOS over the four imbalance categories decreased by a total of 4 percent.

e. EEA 6: What are the effects of incorporating consideration of the availability of the soldiers eligible for promotion, the existence of overfill, the protection of space imbalanced MOS (SIMOS), and other constraints on fill, for each MOS at grades E5 and E6, over time?

RESPONSE. Considering availability of soldiers eligible for promotion, the existence of overfill, and the protection of SIMOS did not lead to improved target methodology. Difficulties were associated with the protection process, in that protecting large MOS in some months of analysis prevented the necessary reduction of numbers needed for promotion to required promotion ceilings.

f. EEA 5: How do alternate target generation processes compare with the current process?

RESPONSE

(1) The current target generation process, in which authorizations are smoothed with a five-point weighted moving average ("current" targets), is distinctly better than an earlier version of the same process, in which authorizations were smoothed using an exponential smoothing technique ("historical" targets). This current target generation process is slightly improved further by different statistical smoothing techniques.

(2) Of all target generation processes evaluated, the process which exists simply as stage 2 authorizations results in the greatest observed increase in percentages of balanced MOS relative to the current process (an increase of 6 percent, grade E5, and an increase of 3 percent, grade E6). Consistent superiority of the stage 2 authorizations relative to the current process, however, does not occur. The stage 2 authorizations are associated with an accentuated underfill in grade E5. A more complex version of the stage 2 authorizations, selective smoothing of stage 2 authorizations identified as outliers and step functions, maintained the same high percentage of balanced MOS observed for the simpler version. Of all target generation processes compared, the complex version of stage 2 authorizations resulted in the fewest shortages; however, it also produced more overages per month than did the current process.

(3) Small superiority to the current process in grade E5 did exist for stage 6 authorizations, the target generation process which is identical to the current process except that smoothing of authorizations is eliminated. A more complex version of the stage 6 authorizations was the "straight line smoothing of stage 6 authorizations identified as outliers." This more complex version improved the small superiority observed for the simpler version. Compared with the current process, percentages of balanced MOS were increased and MOS in categories of underfill and overfill were decreased in both grades E5 and E6.

10. OVERALL FINDINGS. Based on the comparison of distinct target generation processes drawn from alternate processes examined in Chapters 5 through 10, three processes have been identified which show superiority to the current process with respect to the variations in the measurements of fill. No single technique was found superior for both grades E5 and E6.

a. Stage 2 Authorizations. In grade E5, stage 2 authorizations are superior with respect to percentages of balanced MOS. They are inferior, however, with respect to percentages of MOS which are critically imbalanced, underfill, and total numbers of shortages and overages. In grade E6, stage 2 authorizations are superior with respect to both highest percentages of balanced MOS and fewest shortages and overages.

b. Stage 2 Authorizations, Selectively Smoothed. Of all processes evaluated, targets which also exist as stage 2 authorizations, but selectively smoothed for steps and outliers, maintain superiority of highest percentages of balanced MOS. In grade E5, this selective smoothing of stage 2 authorizations also results in the greatest reduction of underfill, but it accentuates overfill.

c. Stage 6 Authorizations Identified as Outliers. In grade E5, the most effective target generation process is generated by smoothing stage 6 authorizations identified as outliers. Although the highest percentages of balanced MOS are not associated with such targets, they do produce the best distribution of percentages of MOS over categories of underfill and overfill and the fewest shortages and overages observed in grade E5.

11. INSIGHTS

a. The Simulation

(1) TARGEN has been a study based on simulation of the total E5/E6 promotion system. As many quantifiable complexities as were known were incorporated into the simulation.

(a) The disadvantage of such a study approach is that it is difficult to track, through the many complexities of the system, the effect a given target has on operating strength.

(b) The advantage of simulating the total system, with all of its complexities, is that the magnitude of the effect which alternate target generation processes have on the total system can be precisely established.

(2) The simulation of the E5/E6 promotion system was useful in establishing relative impact on fill of the different components of the system. In that the current analytical process of reducing numbers needed for promotion to required promotion ceilings does not substantially reduce balanced fill, it is an effective process. It was also observed that discrepancies between the promotion determination and actual numbers promoted are associated with substantial reduction in balanced fill.

b. Target Generation Processes

(1) Time was lost exploring the original concept motivating initiation of this study: there are distinct patterns of fluctuations in authorizations and different statistical smoothing techniques should be effective for different patterns. Practical methods of improving balanced fill could not be developed from this concept.

(2) Subsequently, the concept of a target generation process was generalized to consist of variations of the computational stages used in the current target generation process. Certainly, even more general variations of the target generation process could be developed and systematically evaluated.

(3) Explaining the effect on fill produced by computational stages 4, 5, and 6 of the current target generation process is beyond the scope of this study. Authorizations are first moved up (inflated to total Army strength projections) and then back down to meet limitations by grade. In the middle of this contradictory computational process, projections of trainees, holdees, and students (THS) are incorporated. Little is known of the accuracy of these projections. What was observed about this current target generation process, however, is that it does not lead to accentuated underfill or overfill. Stage 6 authorizations, smoothed for outliers, were associated with good distributions of MOS over all categories of fill; extremes in shortages and overages were not reported.

(4) Stages 4 through 6 of the current target generation process clearly wash out the effect of the statistical smoothing of the stage 2 authorizations. That statistical smoothing can be very powerful, however, was demonstrated by the effect it had on the stage 2 authorizations, when subsequent computations on the stage 2 authorizations were eliminated. Statistical smoothing of steps and outliers in the stage 2 authorizations substantially reduced underfill, maintained the high percentages of balanced MOS associated with the stage 2 authorizations, but shifted imbalanced MOS in the direction of overfill.

c. Measures of Fill

(1) Results were evaluated on the basis of four different variations of the measure, fill: numbers, percentages, and strength of MOS in categories of fill and average understrength and overstrength per month. Rather than computing total strength of MOS in each category, it would have perhaps been more informative to have computed total number of soldiers either understrength or overstrength for each of the categories.

(2) Measurement dependent on category boundaries, which can be arbitrarily set, are always potentially misleading. Where so many changes in operating strength occur as a result of uncontrollable complexities which occur throughout the total E5/E6 promotion system, category boundaries as currently used appear to be overly refined.

#145

TITLE: Manpower and Personnel Integration (MANPRINT) Data Base

AUTHOR: Gregory Tarver

ORGANIZATION: US Army Materiel Readiness Support Activity
Lexington, KY 40511

ABSTRACT:

The US Army Materiel Command (AMC) Materiel Readiness Support Activity (MRSA) has, at the direction of HQ AMC and in coordination with HQ Training and Doctrine Command (TRADOC), developed and activated a centralized, automated MANPRINT Data Base. The data base is now on line and provides data base users a quick summary of front end predecessor baseline data valuable in the evaluation and completion of most MANPRINT analyses. The data base will provide information to aid analysts in predicting manning impacts associated with a new weapon system during the Pre-Concept and Concepts phases of the life cycle.

The MANPRINT data base consists of three main files: the End Item File, the Military Occupation Speciality (MOS) File, and the Baseline Comparison System (BCS) File. The data products consist of: (1) End item/component reliability and maintainability data, (2) End item/component MOS requirements, (3) Direct productive annual maintenance man hours by MOS and end item, (4) System safety impacts, (5) Health hazard impacts, (6) Human factors impacts, (7) MOS availability totals, (8) MOS operator task descriptions, (9) MOS maintainer task descriptions, (10) MOS physical performance tasks, and (11) Ad Hoc report capabilities.

The MANPRINT Data Base gives the user the capability for automatically building a BCS outline and provides a repository for hard copy, obscure front end data.

NO PAPER PROVIDED

#167

TITLE: Two Levels vs Three Levels of Maintenance: The Cost!

AUTHOR: R. McGauley

ORGANIZATION: US Army Materiel Systems Analysis Activity
Aberdeen Proving Ground, MD 21005-5071

ABSTRACT:

This paper describes level of repair analyses for four major Army weapon/communication systems using the Optimum Supply and Maintenance Model (OSAMM). The four systems are: HAWK guided Missile, Single Channel Ground and Airborne Radio System (SINCGARS), Single Channel Objective Tactical Terminal (SCOTT), and Global Positioning System (GPS). The analyses compare the costs associated with a strict two-level maintenance concept with the resulting costs of other maintenance alternatives (e.g. three and four level, with and without screening.) The study identifies the sensitivity of the resulting costs to such entities as inaccurate built-in test (BIT); TMDE costs, including Test Program Sets; Depot Capacity; provisioning levels and supply support measures, to include number and placement of test equipment and maintenance personnel; and finally, the impact of repair verses discard. The cost of each policy is assessed not only in terms of dollars, but also in terms of operational availability and system readiness. Finally, the trade-offs necessitated when considering currently fielded systems will be addressed.

Vivisection of a Deployment Model

Mr. Hugh A. L. Dempsey

US Army TRADOC Analysis Command

Abstract

SRES, a model for computing assignment of units to ships for deployment from CONUS to Europe, was given to the TRAC Quick Reaction Cell. This model, written in FORTRAN for a personal computer, had a program structure so complex as to defy analysis and modification. The model was translated into the C programming language and ported to an Intel 310 computer, a multi-user computer using the Xenix operating system. Then using structured programming concepts and the Xenix programming tools, the program was rewritten, reducing the runtime to five percent of the original, while simplifying the basic algorithms of the model. The new program is speedy, easily understandable, and readily modifiable.

Introduction

This project was a self-development project in my off-duty time. As the TRAC study data manager, I thought that I should get some hands-on experience with a model and see how the data is manipulated. Not wanting to take on a major model like VIC, I searched for a small model to examine. Our Quick Reaction Cell gave me a copy of the SRES (Surface Reinforcement of Europe Study) model, in FORTRAN, without documentation. (After the project was finished, documentation was found.) SRES was created and used by the 7th Army ORSA cell in determining the shipping time needed to deploy US forces to Europe. An identical, companion model, CSRES, dealing with containerization, will not be discussed. The only significant difference between the two models is that CSRES uses different units of cargo measurement, twenty-foot equivalent units, while SRES uses measurement tons.

This paper reports on the effort to analyze that model, identify the underlying algorithms, and to port the model to the computer system available. The procedure taken was to directly translate the FORTRAN program to the C language, run the program and compare the output to that of the FORTRAN program. Since the two outputs were identical, it was assumed that the new program effectively duplicated the old program. The initial version took about five minutes to run on a heavily used Intel 310 computer, an Intel 80286 multi-user computer running the Xenix operating system.

Problem. The primary goal was to identify the basic OR problem underlying the model: Was this a transportation problem? A stagecoach problem? A knapsack problem? The FORTRAN program was hard enough to read as a program; identifying the underlying OR methodology was impossible.

Why the title, "Vivisection of a Model"? It reflects my approach to modifying of the program: I pared away as much of the program as possible, while keeping it alive. Carefully -- so as to keep the same output -- changes were made to the program using C structured programming concepts so it could be read easier, modified easier, and run faster. Upon completion, the program had been modified to include the following improvements:

-- guarantees the transportation of every unit, if there is at least one ship in the region.
-- simplifies the formatting of input files.
-- handles an unlimited number of units.
-- merges the preprocessor with the main program.
-- simplifies the structure of the program.
-- adds air transport.
-- runs in about four percent of the initial run time.

Model Description.

<u>SRES</u> is basically a peace time model, rather than a war time model. It plays no combat, has no shipping losses. There is no delay for convoy operations nor for port operations. The model uses both NATO and US ships, with all of the ships available for Army deployment; there is no conflict of priorities with the other services or NATO countries.

The original model was designed to provide for up to 400 ships and 50 troop units. Air deployment was not played, but planned for a future enhancement. It has 10 US ports: 3 Gulf ports, 6 east coast ports, and one air port. There is only one generic European destination. Units are processed in priority. The model selects the largest ship that will deliver the unit to Europe in the least time, subtracts the load from the total unit cargo and repeats until the unit has been completely loaded. Any unused cargo space is ignored. A ship, when chosen, delivers the unit to Europe and then always returns to the port of embarkation. The ship's new availability time is computed by adding to the old availability time the round trip travel time plus the time to on-load and off-load the unit at the ports. If the ship is then chosen to carry another unit to Europe, it is then instantaneously moved to the new port of embarkation, without travel time being charged. Ships can only be used in their initial coastal region.

Input files.

-- a ships file, ships.dat, containing the ship number, speed in knots, cargo capacity in measurement tons, the region location (Gulf, East coast, or air field), the arrival date at the port of embarkation, and the load time in days;
-- a units file, units.dat, containing the unit id number, the weight of the cargo to be shipped, the port of embarkation id number, days till unit arrival at the port of embarkation, and the POMCUS priority.

Program files.

-- the program matrix read the ships file, computed the travel time from each port of embarkation to Europe plus the loading time, and generated the intermediate input file, matrix.dat, which contained the ships file information plus the travel time. Travel time was computed only for those ports in the ship's assigned geographic area and written into matrix.dat even if the ship could not go to that port.

-- the program sres read matrix.dat, and loaded all of the ships information into 11 400X1-element matrices and one 400X11 element matrix. It then read all of the units information and loaded that into five 50X1 matrices. The program processed each unit in turn, finding all of the ships that could service that port area, copying the data for those ships into new matrices, computing the travel time for that unit, ship, and port combination, and then sorting the data matrices for the ships in that area in parallel to bring the fastest ships to the top of the matrices. Next the sorted ships data were printed into a debug file so that the sorting could be checked. Now the program assigned the ships in sequence to the unit until the total of the ships' tonnage was equal to or greater than the units cargo tonnage. The data for the unit and the ships to transport the unit was then printed into the output file, and the ships' availability times were updated to account for the unit loading and unloading time plus a round trip between the port and Europe. If there were not enough ships to load the unit, the program reported that the unit could not be loaded, did not assign the ships, and proceeded to the next unit.

-- the program post read one or two output files, as desired, printing on the end of the last output file the quantity and type of ships used to transport the entire force.

Output files:

The model results were printed into the file sresout.dat, containing the units' data and the data of each ship used to load those units.

The results of each ship sort were written out to the debug files, interim.dat.

Methodology. In the initial port, it was observed that some of the program's actions were not necessary and that faster programming algorithms existed than those used. Unnecessary tests were eliminated, for example, a block that ran

```
IF ( A .EQ. 0.0 )
THEN B
ELSE B
```

was rewritten as B. Elimination of modules like these simplified the reading of the model code plus speeding up the operation.

Many of the program's variables had non-descriptive FORTRAN type names, such as XKDEL and KREC; throughout the project, as the purpose of the variable was determined, they were renamed to more descriptive names such as speed, loadtime, and delay.

In reading input, the FORTRAN program required strict formatting; if a character was out of place, the program didn't run correctly. C programs are more forgiving of formatting and the C version will accept any numbers separated by white space. For example, the C program would accept a floating point number of 16., 16.2, or 16.23; it's not necessary to specify the number of decimals that will be read.

After porting the program to C, the program was compiled with the profiling option activated. The program was run and the output files were compared with the reference version using two Unix utilities, cmp and diff. If there was any deviation in output, the program was revised. Then the program profile was examined to identify modules which might allow an improvement in run time.

An abbreviated profile is displayed below. At mid-project, the computer was upgraded to the Intel 80386 chip. All times shown below are for the program when run on the Intel 80386.

Profile, sres1.c

name	%time	cumsecs	#call	ms/call
_main	35.1	11.84	1	11844.76
__fcmp	21.5	19.09		
__print	15.8	24.23		
_fcvt	6.4	26.59		
_modf	5.0	28.27		
. . .				
sysnx	0.0	33.75		

From this profile, you can't identify potential for any speed improvement. The largest percent of the time is spent in the main routine with no further explanation. To be able to use the profiler to identify modules worth working on, we need to have them in separate functions, and in this case, there were no user written functions in the program. As the first step, I moved the sort routine into a function so that I could see how often it was used and how much time it took. I also moved the routine that computed the ship time needed to off- and on-load into a function, shipoff.

Profile, sres2.c

name	%time	cumsecs	#call	ms/call
_ssort	33.5	11.30	15	753.43
__fcmp	21.8	18.66		
__print	14.6	23.60		
_fcvt	8.0	26.31		
. . .				
_main	0.9	32.14	1	300.04
. . .				
_shipoff	0.0	33.78	83	0.00
. . .				
sysnx	0.0	33.78		

This actually took 0.03 seconds longer to run, probably due to the function call overhead. shipoff uses so little time that it's not worth revising, but the sort routine is the biggest time user. In fact, without the sort routine, main uses less than one percent of the run time.

In the sort routine, when a faster ship was found, its time was copied into a temporary variable, the slower time was copied into the array slot previously held by the faster ship, and then the faster time was copied into the array slot one level higher than it had been. This was then repeated for each of the other attributes of the faster ship. Instead of doing all of this copying, it's much faster to create an index array and to sort the index, then use the index on all of the attributes. Creating and sorting an index gave me my third version.

Profile, sres3.c

name	%time	cumsecs	#call	ms/call
_ssort	35.3	12.28	15	818.89
__fcmp	21.1	19.63		
__print	16.0	25.19		
_fcvt	7.2	27.69		
. . .				
sysnx	0.0	34.77		

This change caused the sort function to take even longer and actually slowed the program down from 33.78 seconds to 34.77 seconds.

I then replaced the attribute arrays for the ships with arrays of structures. A structure in C is called a record in some other programming languages. A C structure is a variable that holds other variables of possibly mixed types. For example,

```
struct sship {
     int iship;           /* sres ship number                  */
     char sloc;           /* ship's region/coast
                             location assignment               */
     float ston;          /* ship's tonnage                    */
     float time[10];      /* travel time from each
                             port to europe including
                                on- and off-load time            */
     float delay;         /* ship availability at the port */
     float stime;         /* max tvl of ship/unit
                             from port to europe               */
};

struct sship ship[MAXSHIPS];
```

Until this time the program copied the portion of ship array for that port into a separate array and then sorted that new array. Following that it selected ships to transport the unit from the new array. Copying data wastes time; it is faster to create a array of pointers to the ships that are assigned to that region and to access the data through those pointers. I also created an auxiliary function, comp, to help with the sort for the fourth version. This allowed me to see how much time was spent in the sort and how much in the comparison of numbers.

Profile, sres4.c

name	%time	cumsecs	#call	ms/call
--fcmp	18.9	6.16		
_comp	17.7	11.94	119116	0.05
__print	15.3	16.94		
_ssort	13.6	21.39	16	277.58
. . .				
sysnx	0.0	32.68		

This version gave our first program speed reduction to 32.68 seconds, about three percent of our reference version. I also eliminated the comp function to save its overhead time, giving us a run time of 30.68 seconds, another improvement.

Profile, sres5.c

name	%time	cumsecs	#call	ms/call
_ssort	27.5	8.44	16	527.65
__fcmp	22.6	15.38		
__print	17.8	20.85		
_fcvt	7.6	23.18		
. . .				
sysnx	0.0	30.68		

At this point, I replaced the bubble sort function with a heapsort function. A bubble sort is known to be an O(N*N) algorithm, while the heapsort is an O(N*logN) algorithm.

Profile, sres6.c

name	%time	cumsecs	#call	ms/call

__print	28.9	5.52		
_fcvt	12.1	7.82		
_modf	8.8	9.49		
_swap	6.9	10.82	26835	0.05
_siftdown	3.5	14.88	3577	0.19
...				
_siftup	1.5	17.39	3577	0.08
...				
_heapsort	0.2	18.98	16	1.88
...				
sysnx	0.0	19.08		

This now reduced the run time to 19.08 seconds, a 43 percent reduction. However, the program no longer gave the same output as the reference version. The order in which the ships were chosen was different. This is because the heapsort is not a stable sort; it sorts correctly on the given field, but may change any order within the key field. Furthermore, the biggest time consumer now was the __print function, using 29 percent of the run time. Examining the output files, we see that the model results take 6 Kbytes, while the debug file takes 254 Kbytes. Since the debug file contained only the results of the sort routine and that result was different from the reference version, I decided to drop any printing to the debug file.

Profile, sres7.c

name	%time	cumsecs	#call	ms/call
_swap	25.7	1.51	26950	0.06
__fcmp	11.9	2.21		
_atof	11.2	2.87		
_siftdown	10.8	3.51	3581	0.18
...				
_siftup	4.1	4.41	3581	0.07
__chkstk	3.9	4.64		
__print	3.8	4.86		
...				
_heapsort	0.3	5.83	16	1.25
....				
sysnx	0.0	5.88		

That dropped our print time from 5.52 seconds to 0.22 seconds, but dropped our overall run time from 19.08 seconds to 5.88 seconds. This large change resulted since other system functions such as _fcvt -- which converts a floating point number for printing -- are called by print; reducing the calls to print reduced the secondary calls to other functions..

Now the heapsort functions, _swap, _siftdown, and _siftup were the largest time consumers. When assigning the ships to the unit, the model only used a ship once. For example, if it took six ships to transport a unit and there were only five ships available, the model would report that it didn't have enough ships for this unit, assign none and go on to the next unit. This struck me as non-realistic. I would expect that the unit would be loaded on the five ships and one ship would return to pick up the rest of the unit.

Another point is that we are making about 34,000 function calls to do the sorting, but we are only assigning about 90 ships out of 240. It would be faster to do a brute force search of the file for the fastest ship and repeat until the unit is loaded. Using a search algorithm instead of a sort algorithm also eliminates the problem just mentioned. All ships would be available for use; even if there was only one ship per region, all units would eventually get transported.

Profile, sres8.c

name	%time	cumsecs	#call	ms/call
_atof	17.7	0.50		
__fcmp	16.3	0.96		
__innum	15.4	1.40		
_doscan	12.2	1.74		
_fastest	7.8	1.96	88	2.50
...				
sysnx	0.0	2.82		

Replacing the heapsort functions with a search function, fastest, dropped the overall time from 5.88 seconds to 2.82 seconds, with _atof being the new big consumer. _atof converts ASCII numbers to floating point numbers, and is called when the model reads the input files. The input file, matrix.dat, contains many zero values.

---

matrix.dat

1	1	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	-4.0
2	2	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	-4.0
3	3	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	-4.0
4	4	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	-4.0
5	5	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	-4.0
6	6	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	0.0
7	7	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	0.0
8	8	E	27.3	0.0	0.0	0.0	0.0	10.1	9.9	9.6	9.4	10.3	9.4	0.0	0.0

. . .

The zero values signify that the ship doesn't use that port; however, the model doesn't use that information. If we could eliminate the reading and conversion of all those zeros, we could save that wasted time. In fact, it would be convenient if we could eliminate the reading and conversion of most of those other numbers. It seemed to me that I could combine the preprocessor, which used the distances between ports and ship speed to calculate how long the trip would take, with the model, I might save time, since calculation of numbers is faster than reading and converting them.

Profile, sres9.c

name	%time	cumsecs	#call	ms/call
__fcmp	23.0	0.34		
_fastest	21.6	0.66	85	3.77
_main	10.8	0.82	1	160.02
...				
sysnx	0.0	1.48		

The result is a run time of 1.48 seconds, a reduction of 96 percent from our initial run time of 33.75 seconds. The model results are the same as the reference version.

I then added in the capability for deployment by air, adding one unit and six planes: the run time is 1.52 seconds.

Profile, sres10.c

name	%time	cumsecs	#call	ms/call
__fcmp	22.4	0.34		
_atof	13.2	0.54		
__innum	10.5	0.70		
_fastest	10.5	0.86	85	1.88
...				
sysnx	0.0	15.20		

Postprocessor. Instead of translating the postprocessor, post, from FORTRAN to C, I rewrote it in the "AWK" programming language.

```
awk '
NR < 4 {next}
NF != 10 && NF != 5 {next}
NF == 10 {shipno = $6}
NF == 5  {shipno = $1}
{shiploads++}
{reused[shipno]++}
shipno < 8    { ship["FSS"]++ ; next}
shipno < 99   { ship["US RO/RO SHIPS"]++ ; next}
shipno < 199  { ship["NATO RO/RO SHIPS"]++ ; next}
. . .
shipno < 10000 { ship["AIRCRAFT"]++ ; next}
END{
     for (i in ship)
         printf "%35s %5d\n", i, ship[i]
     for (i in reused)
         if ( reused[i] > 1)
             printf "%35s %5d\n", i , reused[i] | "sort -nb"
}' $@
```

AWK is a pattern matching language, wherever it finds a match in the file, it executes the following commands. It has some unusual capabilities; one of which is the ability to use associative arrays. For example, the variable reused is an array and its indices are the shipnumbers. Similarly, ship, is an array, but instead of having integer array indices, ship has indices like "US RO/RO SHIPS", and "US BREAKBULK SHIPS REQUIRED." This makes it simple to read the program and be aware of what it is doing.

Summary and Conclusions. The model underlying the program has not changed; the model is still a peacetime model. However, the program has been simplified as extraneous modules were peeled away. My purpose was to understand, improve, and speed up the program: that purpose was accomplished.

The model uses one of the simplest algorithms for selecting ships: the greedy algorithm. It decomposes the problem to finding the fastest ship to load the next increment of the unit.. Nothing but speed is of interest. However, this is a typical case of suboptimization, where selecting the fastest ship for the next unit increment may increase the total time to deploy the entire force. For example, let a unit have ten more tons to ship. Then if we have two ships of equal speed, one of twenty tons capacity and one of ten tons, the program will pick the first one in the list regardless of size. If the twenty-ton ship is selected, fast ship capacity is wasted and a slower ship may be needed to transport the total force.

I make the following recommendations:

-- that future deployability modeling apply OR tools to the problem. This is a dynamic programming problem: each decision we make in assigning ships and units affects the system state and thereby the subsequent decisions. There should be a objective of transporting the total force in minimum time.

-- use both a source and destination for the units and ships. It will be relatively easy to allow the ships to be redeployed from port to port as needed.

-- combine the container ship program with the basic program. The unit can have two cargo fields: one for standard ships and the other for container ships.

OPERATIONS RESEARCH PROGRAMS
AT THE AIR FORCE INSTITUTE OF TECHNOLOGY

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INTRODUCTION

The Air Force Institute of Technology (AFIT), located at Wright-Patterson AFB, Ohio, has been the Air Force's primary source of technical graduate education for almost 70 years. It currently consists of three schools: Engineering, Systems and Logistics, and Civil Engineering. The School of Civil Engineering provides training courses for personnel who maintain and manage the physical facilities of an air base. The School of Systems and Logistics offers a wide variety of short courses in supply, maintenance, logistics, management, and law to support Air Force needs. In addition they also offer several 15-month educational programs leading to master's degrees in the above disciplines.

The School of Engineering dedicates in excess of 95 percent of its efforts to graduate education and the remainder to technical continuing education programs. The school is organized into five academic departments: Aeronautics and Astronautics, Electrical and Computer Engineering, Mathematics and Computer Sciences, Engineering Physics, and Operational Sciences. The Department of Operational Sciences currently offers two programs leading to a master of science degree in operations research. These are the Operations Research Program and the Strategic and Tactical Sciences Program. For approximately the last ten years, Army officers have been attending and graduating from these two operations research programs.

Wright-Patterson AFB, located near Dayton, Ohio, is one of the largest Air Force installations in the country. It is the home of Air Force Logistics Command which is responsible for maintaining and supporting Air Force systems all over the world. In addition, several major tenant organizations are also at Wright-Patterson. The Aeronautical Systems Division is responsible for the design, development, and purchase of all aircraft and flight simulators, and many of the subsystems normally found aboard the aircraft. The Wright Research and Development Center is also located at Wright-Patterson AFB. This is a complex of many laboratories doing advanced research in the areas of propulsion, materials, flight dynamics, and avionics. Finally, the Foreign Technology Division is also a tenant at Wright-Patterson AFB. This organization provide technical assessments of foreign aircraft, space systems, and technology bases. All of these facilities and organizations work with AFIT on a frequent and regular basis in the conduct of research by both students and faculty.

THE GRADUATE OPERATIONS RESEARCH PROGRAM

The purpose of this program is to educate Department of Defense (DoD) officers in the area of Operations Research. The program is designed to provide an extensive background in systems analysis, economic analysis, probability and statistics, operations research techniques, and related disciplines. The Graduate Operations Research Program at AFIT is unique with its emphasis on the application of operations research techniques to DoD problems. The program prepares officers for analysis roles to assist decision makers in allocating resources for the planning, development, acquisition and use of military systems. To ensure its relevance to DoD, needs, the program is continuously reviewed by employers of the program's graduates.

The Typical Student

The students who enter this program are typically lieutenants and junior captains, although some junior majors have graduated from this program. Most students have undergraduate backgrounds in mathematics, computer science, operations research/management science, engineering, or the physical sciences. Most students have had at least one other assignment as an officer prior to reporting to AFIT. In addition to Air Force personnel, classes usually have two or three Army officers, and several international officers. An entering class typically has 20-25 students, but average class size in classrooms is typically smaller.

The Curriculum

The GOR program is 18 months long and consists of six quarters preceded by a one month review session. A thesis is required of all graduating students. Course work consists of a core of required mathematics, operations research, and economics courses, as shown in Table 1.

TABLE 1 -- Operations Research Required Core Courses

Numerical Methods
Mathematical Methods
Theory of Probability
Mathematical Statistics
Operational Sciences Seminar
Linear Programming and Extensions
Deterministic Methods
Stochastic Methods
Military Systems Simulation
Economic Analysis I & II
Analysis for Defense Decisions

In addition, a full range of electives are offered. Three electives must be taken from one of five emphasis areas, which are shown in Table 2.

TABLE 2 -- Operations Research Emphasis Areas

Advanced Operations Research
Operational Modeling
AI/DSS/Decision Analysis
Applied Statistics/Reliability
Economics

Another three electives may also be selected by the student to focus on research interests, future job responsibilities, or personal interests. Finally, it is possible for students to elect to stay on for an additional quarter for a Command and Control Option. This requires that students take additional courses in knowledge systems engineering, command and control decision making, application of database management systems, and an additional elective.

Assignments

Upon completion of the program, assignments are made by each service for their personnel. Army graduates are normally assigned to the MAJCOMS, HQ DA, TRADOC, or to various joint commands as FA49 officers.

THE GRADUATE STRATEGIC AND TACTICAL SCIENCES (S&TS) PROGRAM

The purpose of this program is to educate DoD officers in the area of strategic and tactical planning and analysis. Specifically, the program prepares military officers for assignments involving selection, planning, and optimization of the deployment and use of conventional and nuclear weapon systems. The program draws heavily upon quantitative analysis techniques and weapon systems engineering applied to the "art of war." The program presents a new operations-oriented, quantitative discipline -- a discipline which is certainly unique in the western world. The main emphases of the program are on scientific approaches to strategic and tactical operations planning. The curriculum includes individual and class exercises in planning, employment, and targeting problems for both strategic and tactical scenarios. As an important by-product of the program, faculty and students, through their research, provide a valuable input to the development and evaluation of technical aspects of military doctrinal tenets.

The Typical Student

Most students entering this program are captains through junior majors and have had prior assignments in operations. For the Air Force, this means most students have a prior background as pilots, navigators, missile launch officers, weapon system controllers, etc. Army officers usually have prior experience in infantry, armor, air defense, etc. Incoming classes usually have 15-20 students and average class size is usually somewhat smaller. A technical undergraduate degree is required and a degree in engineering is preferred.

The S&TS graduates are oriented toward the technical aspects of applying analytical techniques to combat operations. They are taught probability and statistics, operations research, nuclear and conventional weaponry, electronic warfare, and command, control, and communications. These graduates are capable of mathematically modeling and simulating various operational situations, including war or peace-time scenarios. They have both the analytic skills and operational experience to understand complex weapon systems and to investigate alternative operational concepts for using these systems. S&TS graduates are prepared to participate actively on teams and groups responsible for selecting, planning, and optimizing the deployment and use of both conventional and nuclear weapons and to conduct quantitative research in these areas.

The Curriculum

The curriculum is a merger of three academic areas: operations research (with an emphasis on the quantitative sciences), military operations, and weapons engineering. The program draws heavily on quantitative analysis techniques and weapons systems engineering, both of which are then applied to the "art of war." The courses in the areas of quantitative sciences and military operations are considered to be the "core" curriculum which is required of all officers completing the program. These core courses are shown in Table 3. It is also possible for students in this program to extend for an additional quarter for the Command and Control Option.

Because of the inherent specialization of weapons systems within each operational command in the Air Force and other services, the S&TS program offers three specialization sequences: tactical, strategic, and airlift. The Tactical Forces specialization sequence emphasizes modeling of land combat; the survivability, vulnerability, delivery and terminal effects of conventional weapons systems; and nuclear weapons effects in a tactical environment. The Strategic Nuclear Forces specialization sequence emphasizes survivability, vulnerability and effects of nuclear weapons; and surveys the survivability, vulnerability, delivery and terminal effects of conventional weapons systems. The Airlift Forces specialization sequence emphasizes modeling of transportation systems in addition to weapons effects courses.

TABLE 3 -- Strategic and Tactical Sciences Core Courses

Mathematical Methods
Theory of Probability
Nuclear Weapons Physics
Linear Programming & Extensions
Communications for Command and Control
Effective Computer Programming
Mathematical Statistics
Deterministic Methods
Operational Sciences Seminar
Operations Planning Problems
Military Systems Simulation
Stochastic Methods
Systems Analysis and Defense Planning
Electronic Warfare

Assignment

Graduates of this program are assigned by their respective service, just as graduates of the Operations Research Program are. Organizational positions suitable for S&TS graduates are those requiring both operational experience and quantitative analysis capabilities. Such positions include those in studies and analysis, mission area analysis, operations planning, operational analysis, strategic targeting, simulation and analysis, weapon system evaluation, combat concepts, etc. Many of these positions are located at major operating commands, major test agencies, or the Pentagon.

THESIS REQUIREMENTS

All AFIT graduates are required to complete a thesis. Normally, theses are completed on an individual basis but, for appropriate topics, group theses are possible. Thesis work is normally done in the last nine months of the program, with a total of 12 quarter hours allocated to this effort. Many potential thesis topics are provided to students by instructors, guest speakers, and numerous sources throughout the program. The intent of the thesis is to allow the student to demonstrate proficiency at independently addressing and solving a reasonably complex problem. The emphasis is on showing mastery of course material in a new, challenging area rather that on advancing the state of the art.

Applied Focus

Most student theses at AFIT have an applied, rather than theoretical, focus. Topics are normally sponsored by DoD agencies and are usually problems that the agencies have been unable to solve due to lack of time, funds, or expertise. This applied focus allows the student to work with a significant, DoD-related problem rather than one of only academic interest. This generally motivates the student while satisfying academic requirements for a thesis. In addition, it often provides much-needed and timely work for the thesis sponsor. It is not uncommon for AFIT to receive letters from thesis sponsors thanking the Institute, the students, and the faculty advisor for the thesis effort. Many letters cite cost savings in excess of $100,000 had the study been done by a civilian contractor. Often a thesis topic done for a particular sponsor leads to a job for the student with that sponsor. This is the best of all worlds since the graduating student then arrives at his new job knowing a great deal about this job, his new organization, and the people he will work for. He literally "hits the ground running."

Sample Theses

A sample listing of recent theses completed by graduates of the Operations Research Program and the Strategic and Tactical Sciences Program is given in Table 4. It should be noted that all of these are very applied topics.

TABLE 4 -- Recent Operations Research Theses Titles

Funding the Military Retirement System: A Private Sector Investment Approach to Accrual Accounting

Automatic Liquid Agent Detection: Determining the Distribution of Chemical Agent Droplet Mass

Improving the Survivability of a Stochastic Communication Network

A Methodology for Determining the Survivability of Fixed-Wing Aircraft Against Small Arms

A Taxonomy of Advanced Linear Programming Techniques and the Theater Attack Model

A Methodology for Automation of Tank Allocation

ENTRY PROCEDURES AND REQUIREMENTS

The educational requirements for admission to either program are a baccalaureate degree in engineering, science, mathematics, or other quantitative disciplines, or a degree from a service academy with appropriate major. The undergraduate grade point average should be above 3.00 on a 4.00 scale. All applicants should have taken the Graduate Record Exam Aptitude Test. Minimum scores on this test are 600 Quantitative and 500 Verbal. In addition, all students should have completed calculus through differential equations. The academic eligibility of each applicant is based on a review of his/her academic credentials by the AFIT Director of Admissions and the School of Engineering. Some of these requirements can be waived if there are only minor deviations from the requirement and other evidence suggests that a student will be successful in this program. Waivers are granted on an individual basis only after all required information is received by the Director of Admissions.

To apply for entry into either of these programs, the following documents must be submitted to the Director of Admissions:

a. An official transcript from each undergraduate institution attended.

b. A copy of scores from the Graduate Record Examination Aptitude Test.

c. A statement indicating which programs the student would like to be considered for. All of these documents should be sent directly to:

Director of Admissions
AFIT/RR
Wright-Patterson AFB Oh 45433-6583

Questions regarding admissions can be answered by calling (513) 255-7168 or AUTOVON 785-7168. Questions regarding the technical content of either program can be answered by calling the Department of Operational Sciences at (513) 255-3362 or AUTOVON 785-3362.

OTHER PROGRAMS

In addition to the Operations Research Program and the Strategic and Tactical Sciences Program, the School of Engineering offers two other programs that require some course work in operations research. These programs are the Space Operations Program, directed by the Department of Operational Sciences, and the Systems Engineering Program, directed by the Department of Aeronautics and Astronautics. Both programs are heavily oriented toward engineering and somewhat multi-disciplinary in nature with courses in each program being taught by other departments within the School of Engineering.

The Space Operations Program

The purpose of this program is to prepare military officers for management roles involving the use of engineering principles and management science techniques in planning, executing, and evaluating space operations. The main emphasis is on the different scientific areas concerning space operations and quantitative approaches to the planning and execution of space missions. The program is highly interdisciplinary in nature; all students study a series of subjects spanning the areas of space sciences, operational sciences, and management. In addition to this common core of subject matter, each student is required to take a sequence of courses in a specialty area and complete a research thesis on a topic of Air Force interest. Suggested specialty sequences include, but are not limited to, such areas as:

1 Physics
2. Advanced Astrodynamics
3. Spacecraft Stability and Control
4. Propulsion
5. Statistical Analysis
6. Operations Research
7. Reliability
8. Economic Analysis
9. Pattern Recognition
10. Artificial Intelligence
11. Communications
12. Decision Support
13. Space Systems Engineering
14. Systems Management

Entry requirements and thesis requirements of for this program are essentially the same as for the two primary programs previously discussed. As part of their curriculum, students in this program are required to take two courses in management science techniques and a course in computer simulation.

Space Operations graduates can apply management science techniques to the accomplishment of the full spectrum of space missions. They are educated in the areas of probability and statistics, operations research, military system simulation, systems effectiveness/trade-off analyses, management theory, contracting and acquisition and operations planning. They have an understanding of the space environment, orbital mechanics, propulsion and power systems, communications systems, surveillance systems and overall systems engineering. The Space Operations graduate is prepared to participate actively on teams responsible for the selection, planning, and management of space systems in the execution of military operations.

The Systems Engineering Program

Systems Engineering is the application of scientific and engineering knowledge to the analysis and design of complex systems and their associated components. By system we mean a collection of objects which operate together to perform some function. The goal of the systems engineer is to understand the entire system, its internal structure and its interactions with its environment. This understanding forms the basis for both analysis and synthesis of systems.

Typically, the systems engineer is required to develop system objectives and means of measuring satisfaction of those objectives, create feasible alternatives, and apply rational decision-making procedures to select the best solution. In addition, the large scale problems involved generally require team effort for solution. The systems engineer must be able to understand and integrate contributions from other specialists, as well as make their own contributions. Thus, the systems engineer must be a generalist, with a broad interdisciplinary background, but with depth of knowledge in a particular specialty. The Systems Engineering curriculum at AFIT is structured to develop such a person.

Entry requirements and procedures for this program are essentially the same as for the other programs discussed. However, all incoming students in this program are required to have an ABET accredited baccalaureate degree in any engineering discipline. The multi-disciplinary curriculum of this program requires courses in linear programming, systems optimization, and military systems simulation. Specialty sequences are offered in reliability engineering, operations research, systems simulation, and systems theory. A second specialty sequence is also offered in a wide variety of engineering disciplines.

In lieu of an individual thesis, the Systems Engineering Program requires a group design project, which provides an opportunity to apply the tools and techniques developed in the program to a real design problem. The class is divided into design teams (typically five to eight students per team), each of which works for about nine months on a topic of current interest to the DoD. The resulting project reports are accepted in lieu of individual theses.

PROGRAM COST

All direct and indirect costs for these program are provided through the Air Force budget. Army and Air Force officers attend at no personal expense, other than some minor costs for books and supplies. The Army is not charged directly in any way for its personnel attending any of the AFIT programs. Several Army personnel are on the AFIT faculty and their salary and PCS costs are the only expenses the Army incurs for these programs. Army personnel have attended all programs described except for the Systems Engineering Program. However, there is nothing to preclude Army participation in this program.

SUMMARY

Graduate education in operations research at AFIT is provided primarily by the Operations Research Program and the Strategic and Tactical Science Program. Some operations research education is also provided by the Space Operations Program and the Systems Engineering Program. A thesis or design project is required in all programs. Prospective students can apply to the AFIT Director of Admissions for evaluation. There is no extra cost for additional Army students to attend AFIT beyond the cost of the instructors currently assigned.

CONCEPTUAL DESIGN AND DEVELOPMENT PLAN FOR THE OBSTACLE PLANNER SYSTEM (OPS)

Mr. Phillip L. Doiron
CPT Robert Underwood

U.S. Army Engineer Waterways Experiment Station

Introduction

1. Background The method currently used to plan and analyze the placement of countermobility obstacles in support of Operation Plans is a manual effort that is labor intensive and very time consuming. Typically, an effective system of obstacles must be based on the commander's maneuver plan and must be considered together with covering fire weapons and the terrain and weather conditions. The purpose of such a system of obstacles is to disrupt, turn, fix, or block the advance of threat forces.

2. Field Manual 5-102, COUNTERMOBILITY (Headquarters, Department of the Army 1985), describes the obstacle planning process as having the following tasks:

a. Analyze the mission. The mission is the clear, concise statement and purpose of the task to be accomplished by the command.

b. Analyze the avenues of approach. This includes the processes listed below:

(1) Identify canalizing terrain.
(2) Identify enemy objectives.
(3) Identify hindering terrain.
(4) Determine all avenues of approach.
(5) Re-evaluate avenues of approach and objectives.
(6) Identify key terrain and vital ground.
(7) Determine the enemy force size for each avenue.
(8) Determine enemy force boundaries.
(9) Identify the most dangerous avenue of approach.

c. Analyze engagement areas, battle positions, and locations of weapon systems. This involves the following actions:

(1) Determine weapon and observer lines-of-sight.
(2) Calculate target times in the weapon kill zone.
(3) Calculate number of targets that can be engaged over time.
(4) Adjust weapon systems to maximize kill zone densities.

d. Determine obstacle locations and types and identify the commander's priorities.

e. Determine resources, work sequence, task organization, and coordination.

3. The analysis of unit performance at the National Training Center (NTC), Ft. Irwin, CA, as detailed in "Center for Army Lessons Learned, Vol I Heavy Forces, Fall 88" pages 12-13, has reveiled that:

> "Simultaneously positioning weapons/units, emplacing obstacles, diggin in, and siting target reference points (TRPS) results in engagement areas and obstacles ineffectively covered by fire. On the average less than half of friendly weapons engage the enemy."

In order to help solve this problem the following successful tactics, techniques, and procedures have been identified.

> "The defensive goal must be to destroy the enemy with massed fires. Mass fires by tasking units to destroy the enemy in specific engagement areas versus defending a battle position. Given this clear goal, leaders can easily position weapons/units to mass fires on the enemy. Only then can leaders precisely site obstacles which are effectively covered by fire. Leaders then rehearse the plan to confirm its validity and to ensure that subordinates understand the concept. As such thge most effective priority of work in the defense is normally to:
>
> 1. Eastablish security
> 2. Analyze mission
> 3. Identify avenues of approach using IPB
> 4. Use IPB to determine where/how to kill the enemy
> 5. Site target reference points (TRPs) and engagement areas (EAs)
> 6. Assign TRPs/EAs to units as their mission
> 7. Site weapons, weapons systems and units based on their TRPs/EAs
> 8. Site obstacles
> 9. Rehearse to include fire support and repositioning of forces to confirm plan
> 10. Dig in
> 11. Emplace obstacles
> 12. Rehearse buttoned up in MOPP 4 and at night
> 13. Register indirect fires
>
> Note that 1-9 have to take place very quickly to allow troops time to complete the work intensive 10 and 11. Using the leaders recon as an orders group to wargame and complete the plan will speed up 1-9. Remember that a repositioning plan is doomed to failure unless it is rehearsed as a minimum by all leaders and drivers."

4. To assist the officers tasked with obstacle planning as well as to assist the Army in a faster, more systematic way to perform obstacle planning, there is a need for state-of-the-art software to rapidly perform and integrate the above-mentioned tasks. The Obstacle Planning, Construction, and Reduction Work Package within the Corps of Engineers research and development program includes a software development effort directed toward achieving this goal.

5. Purpose and Scope. The purpose of this paper is to describe the primary objectives of the software development effort and the targeted computer hardware on which OPS will be implemented. Also addressed are the data requirements for OPS. This paper will provide a general description of the logic and assumptions and the output software products that will be generated by the system, as well as, the development and documentation schedules.

6. Coordination. Coordination activities required to develop and demonstrate OPS are described below.

a. Coordination with the US Army Engineer School has been initiated to apprise the school of the development of OPS and to gain their support and input to OPS development.

b. Contacts with Army Engineer units has been established and coordination on the development of OPS initiated. The purpose of this coordination will be to put OPS in the hands of Army users to obtain their feedback on the development of the system. The 5th Engineer Battalion has expressed interest in supporting a field test.

c. The deployment cycle of units going to the National Training Center (NTC), Fort Irwin, CA will be determined. A unit will be targeted for use of OPS during its field exercise. A large leadtime before the NTC rotation will be necessary so that the unit can use OPS and gain confidence in its ability to assist them.

System Objectives

7. The objectives which govern the development of the OPS are listed below. Satisfying these objectives will provide the task force commanders and staffs with an improved combat capability. OPS will provide the capability to optimize the design of the battlefield by providing the ability to graphically portray and analyze various battle positions and obstacle system configurations.

a. A state-of-the-art capability for obstacle planning and analysis that is fast and accurate.

b. A procedure for integration of covering weapons fire and obstacle placement.

c. A capability to evaluate the effects of threat obstacles on US operations.

d. A sound basis for expedient evaluation of likely avenues of approach.

Conceptual Design

8. The OPS is being developed for use in the planning, siting, emplacement, and evaluation of the effectiveness of a system of countermobility obstacles on the battlefield. The system will consist of software modules th[illegible]tomate the obstacle planning process. These software modules will access[illegible]es that represent the realistic battlefield conditions faced b[illegible]ommander. These data include force compositons and capabilities, as well as terrain and weather conditions.

Simulation models

9. The OPS software will consist of five basic modules (Figure 1) that will be carefully integrated. The modules are:

a. Avenues of Approach.

b. Weapon Siting.

c. Movement.

d. Obstacle Emplacement.

e. Obstacle System Effectiveness.

OPS is being designed to consider both the US and Threat obstacle configurations. OPS will be menu-based so that different obstacle types, weapon types, and threat force vehicles/equipment can be easily computed/simulated to determine the resulting countermobility obstacle system effectiveness. The user of OPS will directly interact with three of the modules the Avenue of Approach, Weapon Siting, and Obstacle Emplacement. The measure of effectiveness for nonlethal obstacles (i.e. anti-tank ditches) is the delay time associated with the opposing force (OPFOR) effort to breach the obstacle. The measure of effectiveness for lethal obstacles (i.e. minefields) is the number of vehicles lost due to kills of the OPFOR attempting to cross the obstacle or systems of obstacles as well as the delay time associated with the OPFOR breaching attempts.

Supporting data

10. The data requirements of OPS will consist of: information on the types of units, both US and Threat, that will be involved in the emplacement or breaching of the obstacle system; vehicle performance data will provide the necessary information to make mobility predictions for friendly and threat vehicles; equipment performance data will provide the necessary information to make equipment performance predictions for a given piece of equipment; digital terrain data will be in digital format and will be compatible with current digital terrain databases, as well as with the Tactical Terrain Databases (TTD) when they become available; weather data are extremely important and will be used to support calculations in several of the modules; minefield effectiveness data will be used in the Obstacle Effectiveness module to predict the number of vehicles casualties; breaching data will consist of the time delay for breaching an obstacle; and, weapons data will consist of weapon type, effective range, and arc of coverage, and used in the Weapon Siting module.

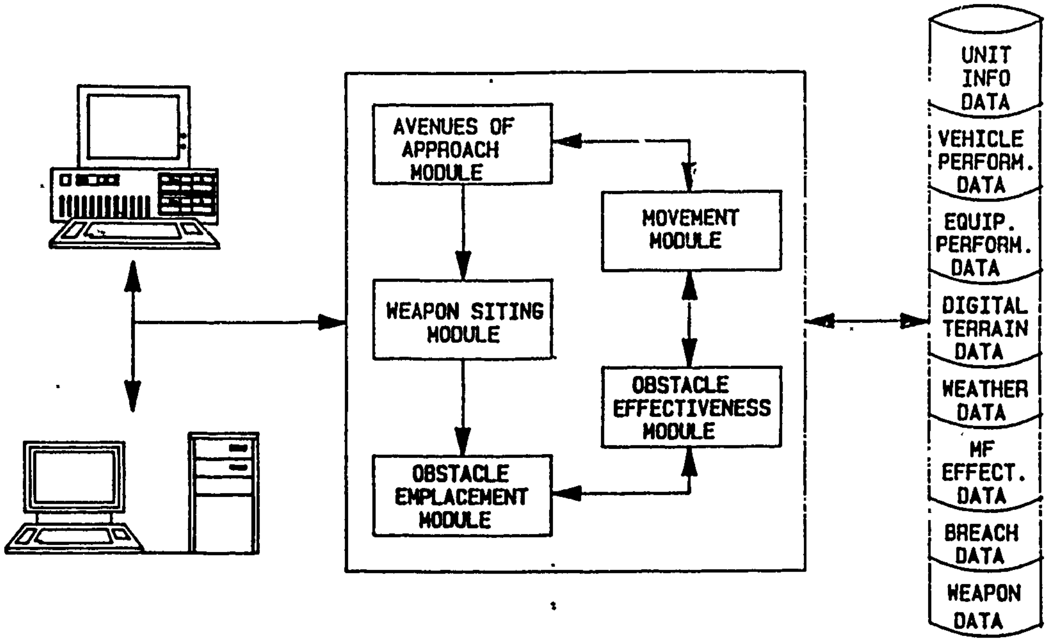


Figure 1. OPS design diagram

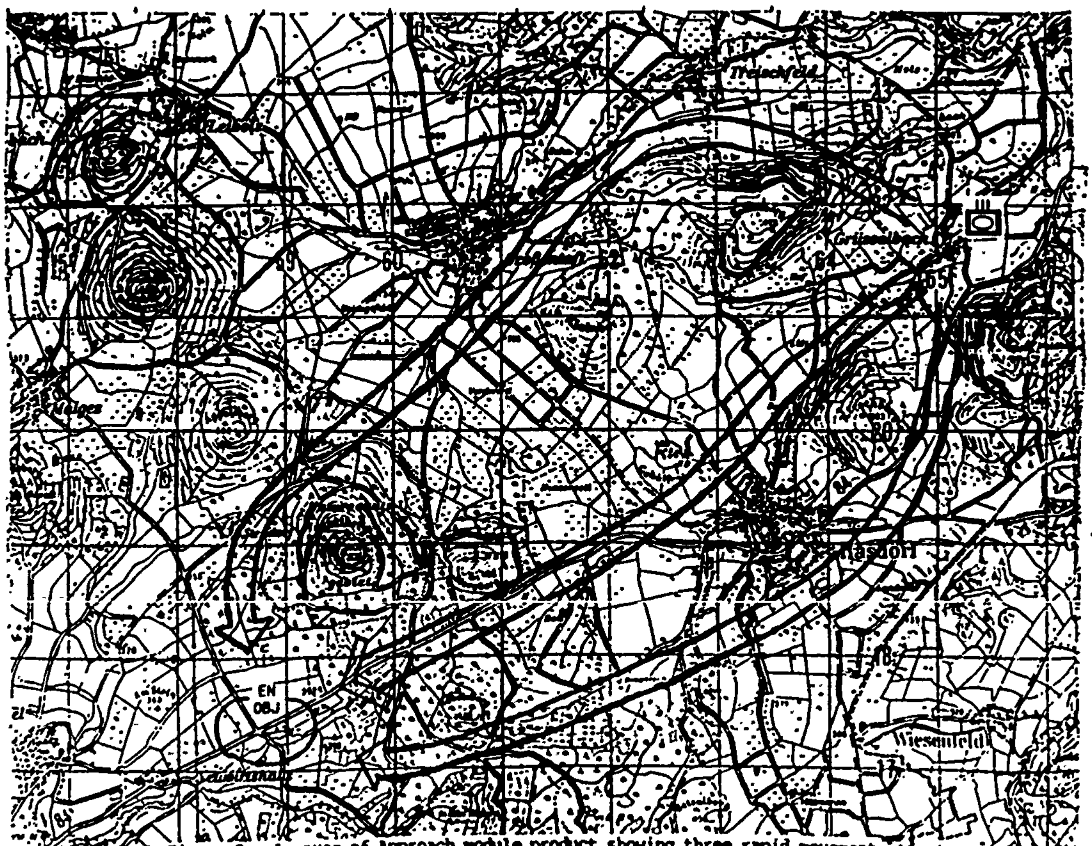


Figure 2. Avenues of Approach module product showing three rapid movement corridors to objective

OPS Hardware

11. The OPS will be developed for a MS-DOS machine (e.g., Zenith 248) that is available to Army units, as well as the Army Tactical Command and Control System (ATCCS), which is based on a Hewlett-Packard 9000 machine.

General Description of the Obstacle Planner System

12. The five simulation modules are described along with additional information including a discussion of the methodology to be used and the products that will be generated by OPS.

Avenues of Approach

13. This module will assist the combat engineer in evaluating the enemy's potential movement routes. This evaluation is dependent on the ability of the existing terrain to support movement of anticipated unit sizes, densities, and compositions.

14. The methodology to be used will consider the geographical area of interest, the terrain and environmental conditions within the area of interest (either actual or statistical), the type of Threat force formation approaching, the Threat's proposed objectives, and the vehicular mix of the Threat force. All of this information will be used (as input) by the software to automatically determine the likely avenues of approach. The determination of the likely avenues of approach will consider the Threat vehicle's mobility, both cross-country and on roads, the transportation (road) network occurring within the area of interest, and the Threat's starting and predicted objective positions. Based on the widths and capacities of the movement corridors and the Threat force sizes that can be accommodated by each corridor, the most probable corridor based on ease of movement will be identified and displayed on the screen (figure 2). The product will include the following information:

a. Threat unit present location.

b. Threat unit objectives.

c. Likely avenues of approach.

d. Most probable avenue of approach.

Weapon Siting

15. Based on the available forces or positions assigned in support of an operations plan, weapon positions will be assigned. The weapon positions will be sited to optimize their effectiveness in accomplishing the unit's mission. This module will assist in the positioning of covering fire forces by determining and plotting lines of sight, based on the effective range of selected direct-fire weapons and selected Target Reference Points (TRP's), all areas where the selected direct-fire weapon systems could be emplaced.

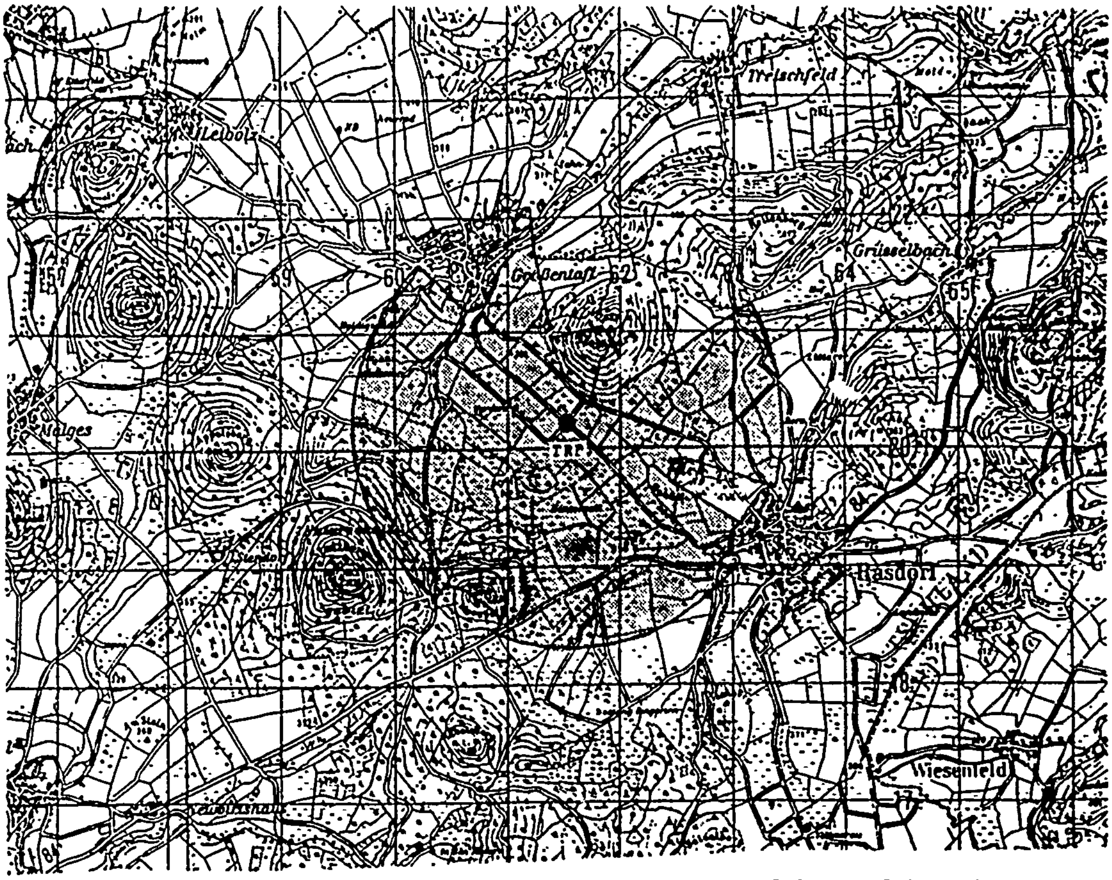


Figure 3. Weapon Siting module product showing Target Reference Point and all possible weapon system locations within 2000 meters

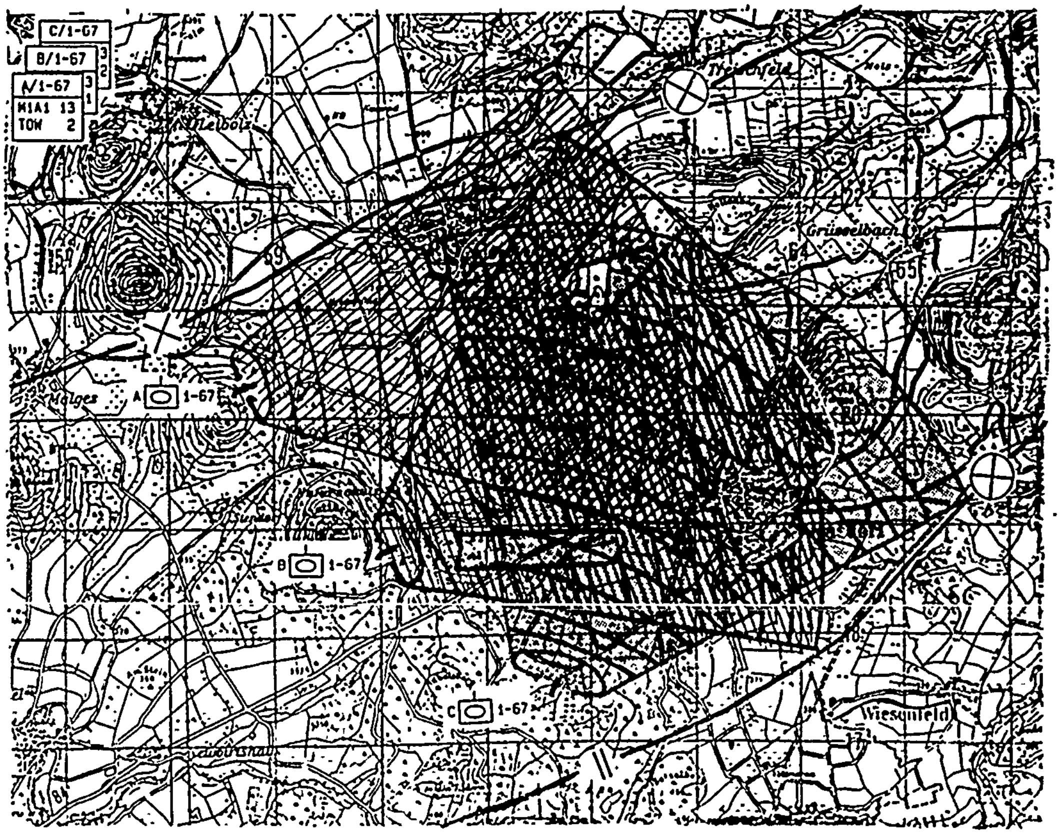


Figure 4. Weapon Siting module product showing weapon fans for force weapons

16. The methodology will be driven by the terrain and environmental conditions occurring on the battlefield, the likely avenues of approach, the TRP's, and the types of weapons. Based on the TRP, all possible locations for each weapon type, based on effective range, will be determined using line-of-sight methods. This product (Figure 3) will enable selection of the primary, as well as secondary weapon locations. This product will be displayed on the computer monitor and will include the following:

a. The TRP's.

b. All possible locations for each weapon type for each TRP.

17. Based on the results of the line-of-sight analysis and the battlefield commander's operations plan, weapon positions will be selected and the resulting weapon fans and density of weapon coverage will be displayed (Figure 4). The product will be displayed on the computer monitor and will include the following:

a. Weapon location, type, and orientation.

b. Weapon fan for each weapon, including dead space (i.e. ground areas masked by vegetation and/or terrain).

Movement

18. The movement module calculates unit movement rates and flows through a network. The network of likely routes through the area of interest is generated by the Avenues of Approach module and can be modified by the system user, if desired. Given the specified force size and composition and its current and anticipated locations, the Movement module will determine the fastest paths and the maximum vehicle flow along the paths through the network. The possible paths can be arranged from fastest to slowest, and data will be generated on the speeds, times, distances, and vehicle flows along each path.

19. The Movement module will interface with the Avenues of Approach and the Obstacle System Effectiveness modules to evaluate the effects of terrain modification (emplacement of obstacles) on the mobility of the threat combat force. The module will calculate best paths through an area with or without man-made obstacles. It will consider the effects of on- and off-road conditions as well as gap crossing capabilities. By analyzing a movement network (as opposed to a series of individual paths), the ability to bypass obstacles is determined.

20. The methodology used is based on the type and composition of the Threat unit, the Threat vehicular mobility as calculated by the Condensed Army Mobility Model System (CAMMS), the network analysis capability provided by the Lightweight Army Mobility Planner (LAMP), the formation used by the Threat unit, and the terrain and environmental conditions on the battlefield.

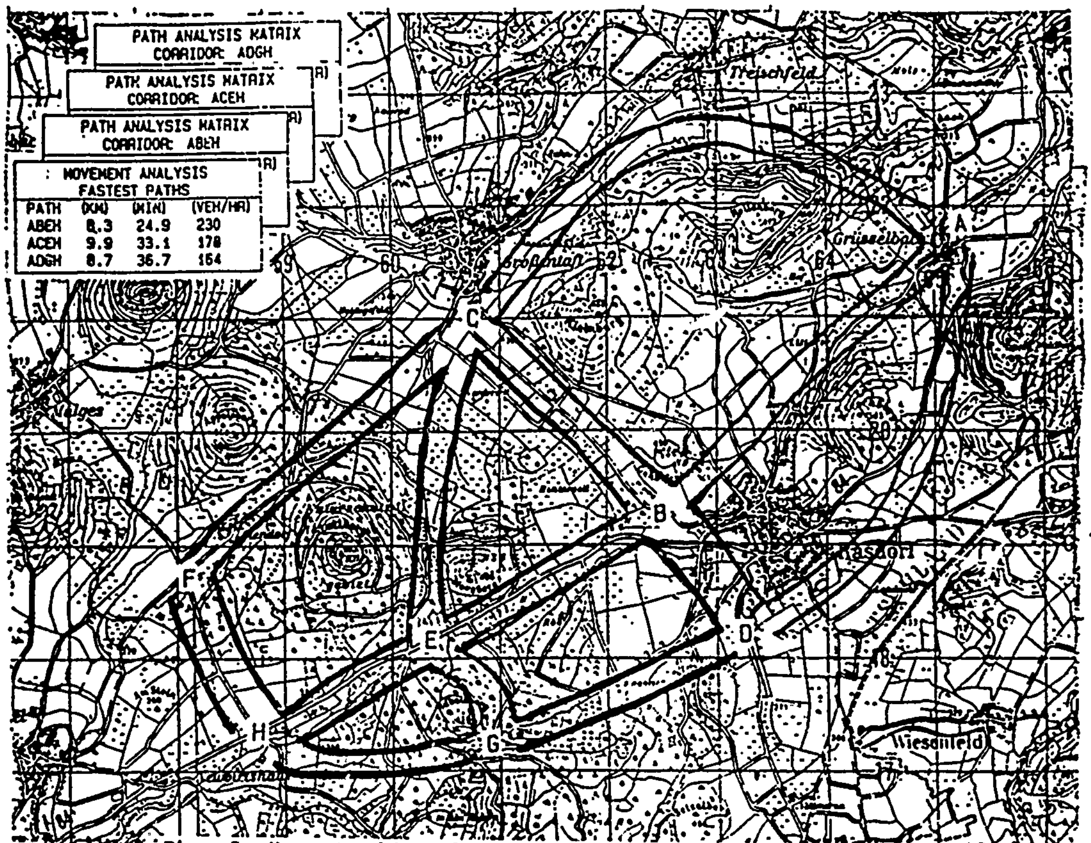


Figure 5. Movement module product showing high movement paths and analysis of [illegible] time and flow

MOVEMENT ANALYSIS FASTEST PATHS			
PATH	(KM)	(MIN)	(VEH/HR)
ABEH	8.3	24.9	230
ACEH	9.9	33.1	178
ADGH	8.7	36.7	164

PATH ANALYSIS MATRIX
CORRIDOR: ABEH WITHOUT OBSTACLES

	SEGMENT			CUMULATIVE		
POINT	(KM)	(MIN)	(VEH/HR)	(KM)	(MIN)	(VEH/HR)
A	0.0	0.0	0	0.0	0.0	0
B	3.9	11.7	250	3.9	11.7	250
C	2.6	7.8	230	6.5	19.5	230
D	1.8	5.4	270	8.3	24.9	230

Figure 6. Details of Movement module movement analysis and path analysis

21. The Movement module uses the paths generated by the Avenues of Approach module to generate a network that is evaluated using operations research algorithms. The network is shown on the computer monitor (Figure 5). The output of this module is shown on the computer monitor as:

a. A network of the likely unit movement corridors through the area of interest. Fastest and highest capacity paths are highlighted.

b. An ordered listing of the fastest paths and the highest capacity paths through the network (Movement Analysis matrix).

c. Phase line locations, times, and vehicle flows across phase lines (Path Analysis matrix).

An example of the information contained in the movement and path analysis matrices are shown in Figure 6.

Obstacle Emplacement

22. This module will be used to determine the resources needed to emplace the selected obstacles. The obstacle type and position will be determined by the terrain and environmental conditions of the battlefield, the density of weapon coverage, the type and composition of the threat force, and the operations plan guiding the combined arms activities within this area of interest.

23. The methodology is driven by the terrain and environmental conditions, the type of obstacle, and the method for emplacing the obstacle. Engineer equipment availability and equipment performance data will be used to determine the resources that will be required and the time to emplace the obstacles.

24. Based on the battlefield commander's operation plan, obstacle types and locations will be determined and entered into the system by the by the user. The supporting engineer unit's TOE and obstacle priority will determine the allocation of the equipment to the task to be performed. The product (Figure 7) will be displayed on the computer monitor and will include the following:

a. Obstacle type.

b. Obstacle location.

c. Obstacle dimensions.

d. Personnel and equipment resources to emplace each obstacle.

Other pertinent information will be highlighted, such as location of command post and ammo supply point.

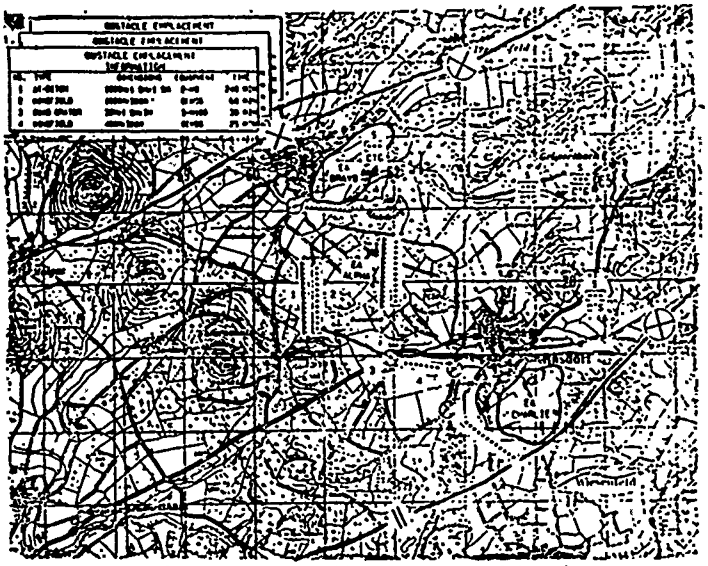


Figure 7. Obstacle Emplacement module product showing obstacle type and location

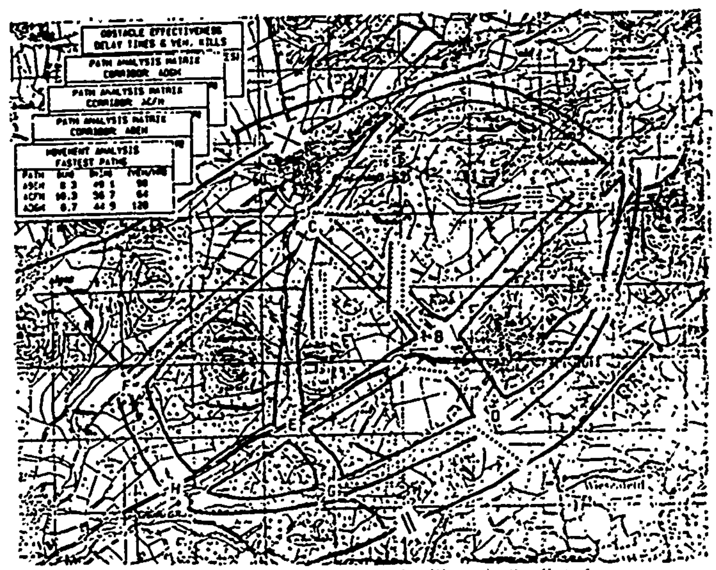


Figure 8. Obstacle Effectiveness module product illustrating the effect of obstacles on movement along avenues of approach

MOVEMENT ANALYSIS FASTEST PATHS			
PATH	(KM)	(MIN)	(VEH/HR)
AGDH	8.7	44.9	120
ABEH	8.3	49.1	98
ACFH	10.3	56.7	64

PATH ANALYSIS MATRIX CORRIDOR: ABEH WITH OBSTACLES						
	SEGMENT			CUMULATIVE		
POINT	(KM)	(MIN)	(VEH/HR)	(KM)	(MIN)	(VEH/HR)
A	0.0	0.0	0	0.0	0.0	0
B	3.9	23.0	120	3.9	23.0	120
C	2.6	20.7	98	6.5	43.7	98
D	1.8	5.4	98	8.3	49.1	98

OBSTACLE EFFECTIVENESS DELAY TIMES & VEHICLE KILLS		
OBSTACLE NO.	BREACHING TIME (MIN)	VEHICLE KILLS (MINES)
1	22	5
2	10	NA
3	30	7

Figure 9. Details of Obstacle Effectiveness module movement analysis, path analysis, and obstacle time delay and/or vehicle kills

Obstacle Effectiveness

25. Once the obstacles have been sited and the resources allocated for emplacement of the obstacles, an analysis of the effectiveness of the system of obstacles is performed. The information generated in the Obstacle Emplacement module is used as input for this module. Obstacles are used to disrupt, turn, fix, or block the movement of Threat forces. Mine obstacles have the additional purpose of attriting the enemy. Effectiveness can be analyzed in the terms of attrition and time delay through the identified movement corridors. Assessments will also be made of the number of vehicle casualties (mobility and catastrophic kills) caused by the various mine systems.

26. The methodology will consider the type of friendly obstacles, weapons sitings, and the Threat unit's breaching force. Threat capability to breach the obstacles will be used to determine the amount of delay time associated with the various obstacles both with and without weapon covering fire. Minefield effectiveness data from the AMSAA will be used to determine the attrition of the Threat due to mines (conventional and scatterable).

27. Based on the delay times associated with the obstacles and vehicle losses due to mines, the movement times and the number of vehicles able to pass through the area will be recomputed by the Movement module.

28. The product produced by this module (Figure 8) will show the effect of the selected obstacles on the movement time and vehicular composition of the Threat force. The Threat obstacle breaching time, as well as the number of vehicles casualties due to minefields will be used to determine the location of the phase lines along the enemy's corridors of advance. This information will be input to the Movement module which will calculate the movement of the Threat force along the avenues of approach. This product will be displayed on the computer monitor and will include the following:

a. Obstacle breaching (delay) times with and without covering fire.

b. Vehicle casualties due to mines/minefields.

c. Display of the movement network.

d. Movement Analysis matrix.

e. Path Analysis matrix.

f. Minefield Effectiveness matrix.

An example of the movement, path analysis and obstacle effectiveness information shown on the product is depicted in Figure 9.

Engineer Command and Control System Interface

29. The OPS will interface with the Engineer Command and Control System (ECCS) by providing as input a list of commander prioritized obtacle locations and types. ECCS will use this list in determining the scheduling and usage of engineer resources in the completion of these tasks.

OPS Development Schedule

30. The development effort will consist of three phases: development of OPS Version 0.5, development of OPS Version 1.0, and demonstration of the first-generation (Version 1.0) software.

Development and field test of OPS Version 0.5

31. The development schedule for FY89 will involve several key activities. These activities will be directed toward producing a quality product and toward gathering information for technical demonstrations of OPS. A development schedule is shown in Figure 10.

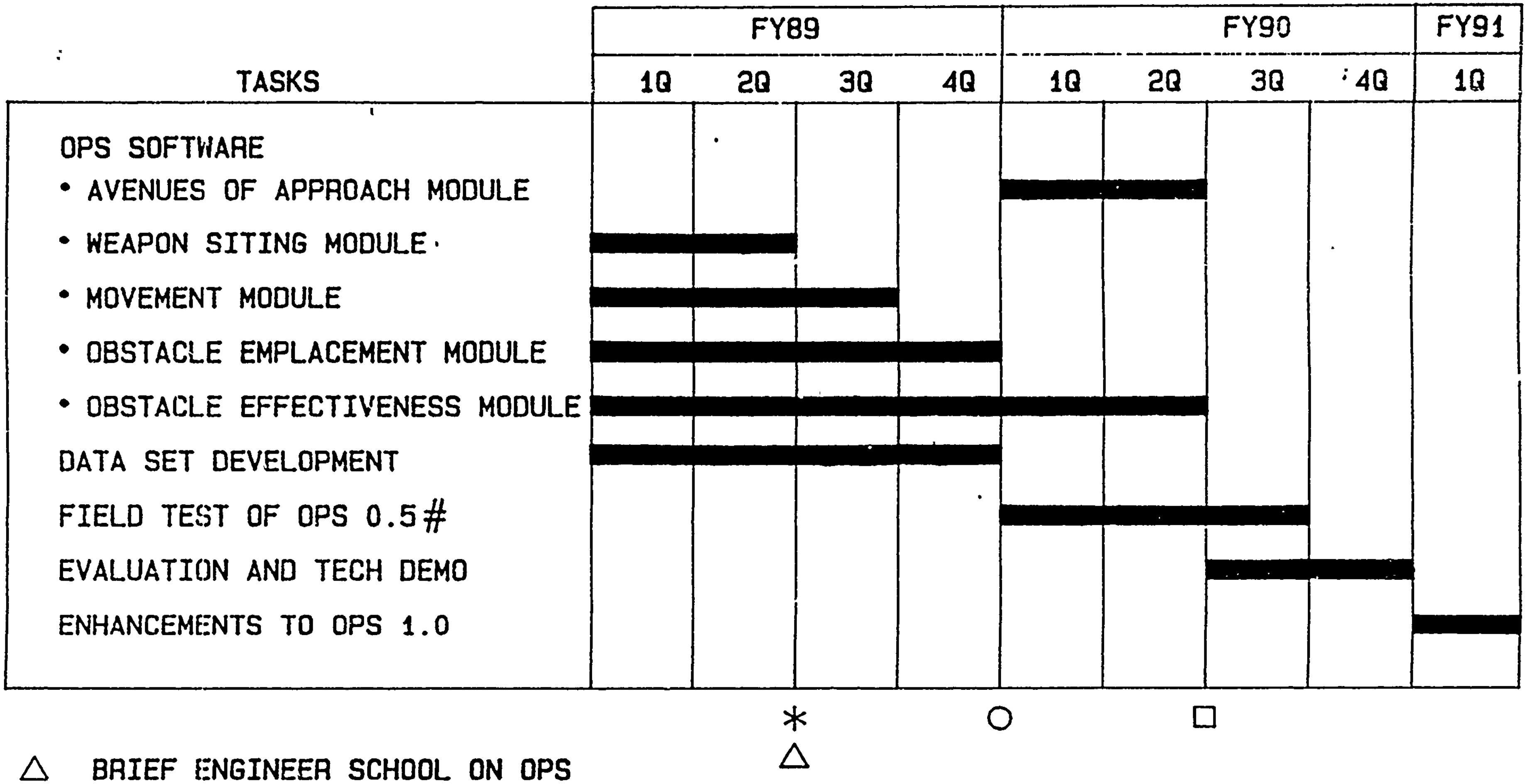
32. During FY89, three of the system modules were completed--Weapon Siting, Movement, and Obstacle Emplacement. The other two modules, Avenues of Approach and Obstacle Effectiveness, will be completed in FY90. The OPS Version 0.5 will be ready for field testing beginning in the first quarter of FY90.

Development of OPS Version 1.0

33. Version 1.0 of OPS will include all five modules. Version 1.0 will then be demonstrated and evaluated by field units. Feedback from the evaluation will then form the basis for further enhancements.

Acknowledgements

34. We would like to gratefully acknowledge the permission from the Chief of Engineers to publish this paper.



△ BRIEF ENGINEER SCHOOL ON OPS

* INITIATE COORDINATION WITH ENGINEER UNITS

○ OPS VERSION 0.5

□ OPS VERSION 1.0

DEPENDENT ON AVAILABILITY OF DIGITAL TERRAIN/WEATHER DATA

Figure 10. OPS development schedule

JOINT OPERATIONAL ASSESSMENT - ENGINEER REQUIREMENTS, EUROPEAN SOUTHERN REGION

Authored by Miss Susan J. Wright
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1. **PURPOSE.** This monograph provides an overview of the study and focuses on the information shortfalls and the support needed from the analytic community to enable the forces going into this region to perform more accurate and realistic operational planning.

2. **BACKGROUND.** In recent years, interest in the northern and southern flanks of the European theater has increased. This can be attributed to the recognition of the vulnerability and importance of each region to the security of Western Europe. The Southern Region, which encircles the Mediterranean Sea, has long been downplayed by the US Army due to a low commitment of ground forces. In the last several years, as a show of support to our Allies in the region, the size of Army forces has increased. MG Lincoln Jones III, Commander of the USA Southern European Task Force (SETAF) and 5th Theater Army Area Command (TAACOM), requested a review of the forces under his command to ensure that they were structured to meet projected requirements. As a result, the USA Engineer Studies Center (ESC) was formally requested to perform an assessment of Army engineer forces in the Southern Region. The assessment would include identification of engineer requirements and a comparison of requirements to existing capability. After the first project review in May 1989, the project was changed to only an evaluation of the engineer requirements, and broadened to include requirements for all four services in the region: Army, Navy, Air Force, and Marines.

3. **OBJECTIVES.** This study's principal objectives are to:

a. Assess engineer support requirements across the entire range of combat support and combat service support operation activities in Europe's Southern Region. Focus will be on engineer support to rear combat zone (RCZ) and communications zone (COMMZ) operations.

b. Establish the priority of engineer support requirements.

c. Quantify engineer requirements by combat zone (RCZ and COMMZ), area wartime construction management (AWCM) region, time of occurrence, and service supported (Army, Navy, Air Force, and Marine Corps).

d. Evaluate host nation (HN) support and other resources, such as contractors, which could effectively reduce identified requirements.

4. **SCOPE.**

a. ESC's research and analysis will consider the primary generators of wartime engineer requirements most critical to the execution of the 4102 and 4360 series of operations plans (OPLANs). The evaluation will focus on two operational areas:

(1) RCZ (i.e., the area to the rear of the major combat maneuver units' rear boundary, but forward of the COMMZ boundary) -- to include a validation of US Army force allocation rules by examination of available host nation infrastructure.

(2) COMMZ (i.e., the area to the rear of the RCZ rear boundary) -- detailed analysis.

b. Engineer requirements will be developed according to the staging area occupation and concept of operations specified in appropriate OPLANs. For the Army maneuver units, time-phased requirements will be developed first in the intermediate staging areas and prepositioning sites in the COMMZ, then forward into the RCZ. For the combat service support units in the COMMZ, time-phased requirements will focus on the development and expansion of the logistics support base. Navy engineer support will relate to the expansion, maintenance, and repair of existing ports and airfields in the region. Time-phased engineer support for the Air Force will center on support at main operating bases, and the expansion of lesser developed air bases as squadrons and wings arrive in the region.

c. Engineer requirements will be analyzed in a conventional battlefield environment with chemical weapons played late in the scenario.

d. Workload requirements and task priorities will be based on the methodology developed in previous ESC engineer assessments,[1] extended and modified as appropriate for the European Southern Region. The study advisory group will determine priority task lists (one for each of the services and one for an overall Southern European Region wrap-up). These task lists will

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[1]"US Army Engineer Assessment, Europe" (S), (ESC, June 1981); "Analysis of III Corps Combat Engineer Wartime Requirements" (S-NF), draft (ESC, October 1984); "Analysis of V Corps Combat Engineer Wartime Requirements" (S-NF), (ESC, December 1983); and "Analysis of VII Corps Combat Engineer Wartime Requirements" (S-NF), (ESC, April 1983) (hereafter referred to as III, V, and VII Corps analyses); "Engineer Assessment, Korea" (S-NF-RELROK), (ESC, September 1987); "Engineer Assessment, Southwest Asia" (S-NF-WNINTEL), (ESC, August 1988).

be based on the relative importance of each task to each US component service and their subordinate commands' operations.

e. The scenario will be used to identify the time-phased deployment of US combat forces and the threat to existing facilities from land- and air-based attacks. These scenario conditions will determine the time-phased requirements for engineer support in the region.

f. Units will deploy in time phased force deployment list (TPFDL) sequence. Deployment will be constrained by each unit's stated not-earlier-than dates and the estimated availability of strategic deployment assets (i.e., ships and planes).

g. The Civil Engineer Support Plans (CESPs) developed by each of the services will be a major starting point in determining RCZ and COMMZ engineer requirements.

5. **TERMS OF REFERENCE.**

a. Study time frame -- 1990.

b. Conflict conditions -- conventional battlefield with chemical weapons used late in the scenario.

c. Conflict duration -- NATO D-day to D+89, with a 10 day warning period prior to D-day.

6. **ASSUMPTIONS AND THEIR SIGNIFICANCE.** The study's major assumptions are listed below.

a. **ASSUMPTION:** D-day will be played as 15 May 1990. **SIGNIFICANCE:** This assumption establishes a reference base for determining manpower and material assets in deploying units as well as climatic conditions.

b. **ASSUMPTION:** Warning conditions and the commencement of AFSOUTH deployments will be played as detailed in OPLANs 4102 and 4360. **SIGNIFICANCE:** This assumption influences the choice of intermediate staging areas, selection of prepositioning sites, and the early deployment capabilities of the US intertheater lift system.

c. **ASSUMPTION:** HN and contract support agreements will remain in force. **SIGNIFICANCE:** This assumption means that, to the extent support agreements exist, HN and contractor labor and facilities will be considered as usable assets in offsetting certain engineer support requirements.

d. **ASSUMPTION:** A mechanism is in place to negotiate with host nations for support during the conflict. **SIGNIFICANCE:** Through analysis of existing HN capability (both labor and facilities) a percentage of HN assets will be considered usable assets in offsetting certain engineer support requirements for those countries where no signed agreements currently exist.

e. **ASSUMPTION:** Analysis of combat operations is limited geographically to Italy, Greece, Spain, Portugal, and Turkey. **SIGNIFICANCE:** Depiction of combat operations in Northern Africa are excluded.

f. **ASSUMPTION:** Engineer support requirements will be determined for all US forces within the AFSOUTH area of operations. **SIGNIFICANCE:** Army, Navy, and Air Force engineer support requirements will be calculated. Marine Corps intermediate staging base requirements may be included in the study if requested.

g. **ASSUMPTION:** All construction will be to initial austere standards. New construction will be limited to hardening of communication facilities, petroleum pipelines, and hardstand for selected facilities such as hospitals. **SIGNIFICANCE:** Using this standard affects the amount of engineer effort needed to complete each task. For example, fuel bladders will be used rather then metal tanks; area will be cleared for tents rather then constructing billets.

h. **ASSUMPTION:** Damage repair will only be performed on select facilities such as airfields, ports, main supply routes, pipelines, and railroads. **SIGNIFICANCE:** War damage to remaining facilities will cause the operations in those facilities to relocate. Engineer support in those cases will consist of site preparation at the new location (or facilities constructed to initial/austere standards).

7. **METHODOLOGY.** The COMMZ engineer assessment follows the general methodology shown in **Figure 1.**

a. **Overview.** There are five major steps to the analysis. First, the engineer support requirements are identified. These requirements are prioritized in the second step. The third step is to calculate and time-phase those requirements over the scenario. In the forth step, the HN and contractor capability is determined for each of the five countries of interest. A comparison of the time-phased requirements with the host nation and contractor capability is also a part of the fourth step in the analysis. Finally, results of the analysis and observations on the type, amount, and cause for select requirements will be presented.

b. **Step 1 - Identify Requirements.** The engineer support tasks are based on the general requirements identified in the series of 4102 OPLANs and the scenario developed for the study. These general requirements are supplemented with specific support tasks obtained from several other sources. Each of the four services' major subordinate commands, the users of engineer support, are asked to identify engineer support tasks. Engineer tasks associated with maintenance and repair of roads, bridges,

STUDY METHODOLOGY

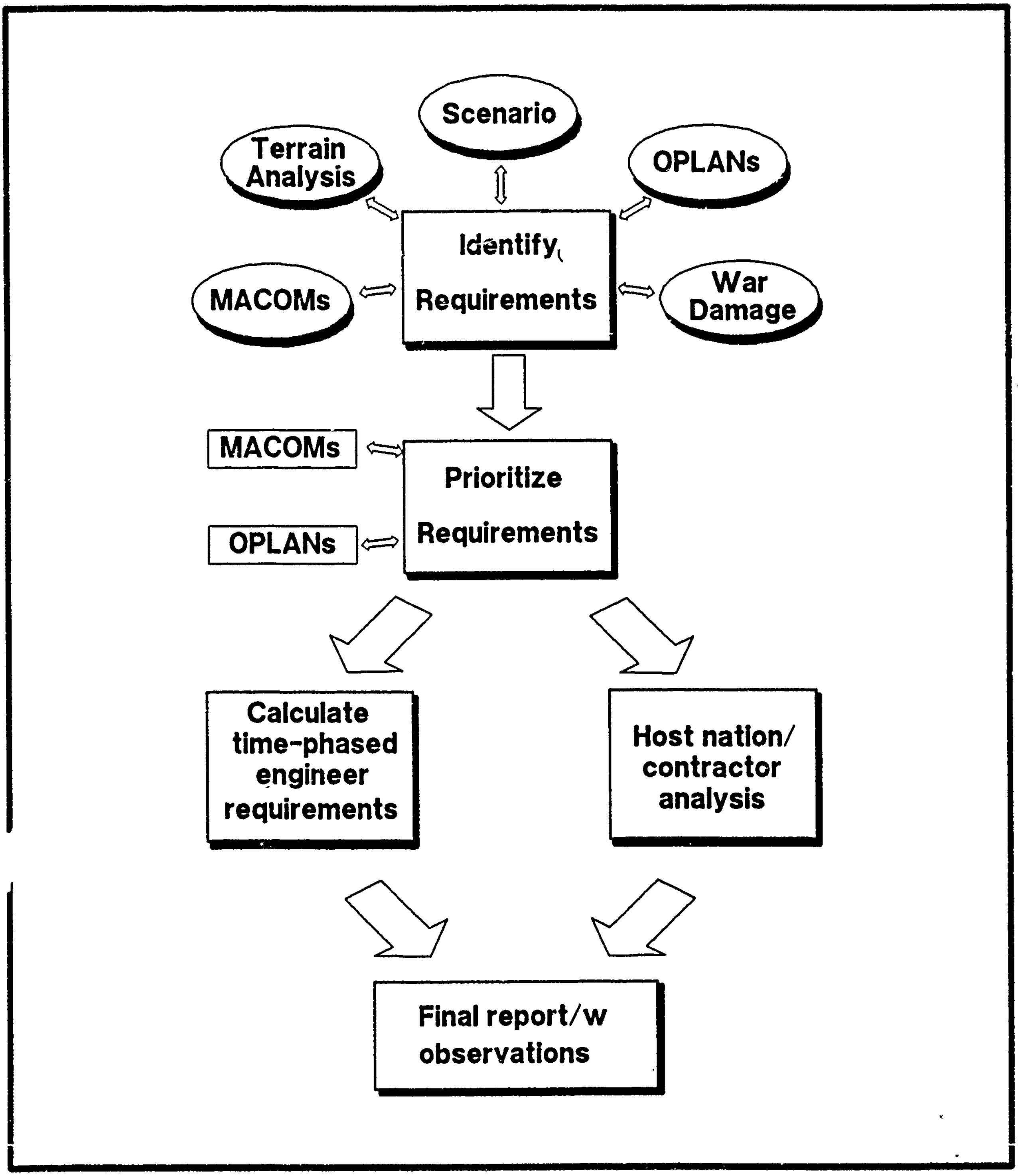

Figure 1.

raillines, and other lines-of-communication such as ports and airfields are determined from a terrain analysis of the COMMZ area of operations (AO). Finally, tasks associated with repair of war damage to existing facilities are determined based on a priority of targets in the region and a threat consisting of air, missile, and covert ground forces.

c. **Step 2 - Prioritize Requirements.** Each of the services arranges the tasks in order of importance, and groups them into three broad priority groups (1, 2, and 3) as defined in European Command Directive 61-4[2]. These priority groups correspond to the effect the tasks have on the existence and continuance of the force. The definitions are given in **Figure 2.**

PRIORITY CATEGORY DEFINITIONS FOR ENGINEER SUPPORT

Category	Description
Priority 1	Indispensable to tactical success Significantly reduces vulnerability
Priority 2	Ensures short-term sustainability Reduces probability of defeat Indispensable to strategic success
Priority 3	Reduces equipment and material losses Enhances force restoration Enhances long-term sustainability

Figure 2

d. **Step 3 - Generation of requirements.** A majority of engineer support requirements in the COMMZ are generated as troops arrive in the theater, as opposed to requirements in the forward combat zone (FCZ), that result from forward edge of the battle area (FEBA) movements.

(1) Time periods. The COMMZ requirement calculations are divided into ten 10-day time periods. The first time period reflects pre D-day preparations. The scenario plays out for 90 days following D-day.

[2] "Construction: Military Construction/Engineering in the USEUCOM Area, Directive 61-4", (Headquarters, United States European Command, 5 February 1986).

(2) Civil Engineer Support Plan Generator (CESP-G). The CESP-G model will be used to determine time-phased requirements.

(a) The model calculates time-phased requirements by one of four methods:

1) Population-related planning factors for supply, ammunition, water, fuel storage, and billeting.

2) Facilities required by specific units such as aircraft units.

3) Total populations within a given area (mainly used for air base facilities).

4) Special projects that cannot be estimated by the other methods, such as pipelines, enemy prisoner of war camps, and hospitals.

(b) Requirements generated for facility category codes. The facility category codes are provided by the Joint Chiefs of Staff Memorandum 235-86.[3] Each category code has a variety of facility components associated with it that the model can select, based on the size of the requirement generated, and the construction standard desired. The facility components are taken from the Army Facility Components System, the Naval Advanced Base Functional Component system, and the Air Force Facility Components System.[4] Each facility component provides the amount of engineer work effort, in manhours, needed to construct a given facility by horizontal and vertical skills and general labor support.

(3) CESP-G updates. ESC will update existing CESP-G data files to tailor the model's methodology to the assumptions of the study.

(a) Planning factors used to determine Army requirements for ammunition and fuel storage; open, covered, and cold depot storage; and ammunition maintenance facilities have been updated based on "Army Forces Planning Data and Assumptions

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[3]"Planning Factors for Military Construction in Contingency Operations, Memorandum from the Joint Chiefs of Staff (MJCS) 235-86", (Joint Chiefs of Staff, 31 October 1986).

[4]These are military engineering construction support systems for planners and commanders to use in selecting, planning and constructing facilities and installations needed in military theaters of operation. They contain facility components that provide some specific type of cover or protection for personnel or unit functions.

(FY 1987-1996)" consumption rates for the European theater.[5] Separate planning factors for enlisted and officer billeting were deleted in favor of one factor for emergency troop housing. Air Force planning factors for various aircraft-related facilities will also be updated.

(b) Manhours for key facility components will be changed to reflect an austere standard of construction. Facility components for war damage repair of existing facilities, excluding airfields, will change to better reflect use of field-expedient repair methods.

(c) War damage factors for critical facilities resulting from either an air, surface-to-surface missile, or covert ground threat are to be added to the model.

(4) Manhours. Requirements in the COMMZ are given in manhours by construction skill: horizontal, vertical, and general labor support. Horizontal personnel are operators of equipment, including dozers, dump trucks, graders, and cranes. Plumbers, electricians, carpenters, pipeline specialists, and masons fall under the category of vertical construction skills. General construction labor support are personnel not requiring a specific skill to accomplish a task.

(5) Geographic region. The COMMZ analysis generates requirements by geographic regions. Requirements are first generated at each base where US forces are located. The bases are then combined into base groups that correspond to AWCM regions. The AWCM requirements are further aggregated into countries: Italy, Greece, Turkey, Spain and Portugal.

(6) Service. Requirements will be calculated for each individual service and then combined for an overall theater analysis.

e. **Step 4 - Host nation and contractor support.** All requirements for facilities that are generated by the CESP-G are offset by existing assets within each base. These assets include both US controlled assets used during peacetime, assets that have be pre-negotiated for wartime use through HN agreements, and NATO sponsored projects. In addition, the study will provide a listing of contractor capability that may be available after D-day to offset needed engineer support.

f. **Step 5 - Observations.** The areas of concern identified in the analysis become the focus of this final step in the engineer assessment. The results of the calculations will be

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[5] "Army Force Planning Data and Assumptions, FY 1987-1996 (AFPDA FY 87-96)" (S-NF-WNINTEL-NOCON), (US Army Concepts Analysis Agency, August 1986).

presented in varying levels of detail based on consolidation to meet sponsor needs. For example, there will be separate monographs for each service that will present the data by individual task and priority for each base. This individual service data will be consolidated and presented by task groupings and priority for the AWCM regions. Further consolidation will provide results for each country and finally data for the overall Southern Region AO.

8. **STUDY LIMITATIONS.** In the process of the initial research for the study, it was found that much of the data did not exist, was outdated, or was just beginning to be developed. This includes such major items as: terrain information, incomplete planning by forces, changing units and missions, scenarios, and war damage models.

a. Terrain data for several countries dates back to the 1940s. The forces assigned to the Southern region, especially Army ground forces, are in a constant state of flux. Many units do not have this AO as their primary mission restricting their ability to train and plan for operation in the region.

b. Due to political tensions between our allies in the region, much of the information normally available for planning purposes is classified to keep neighboring countries from finding out each others' capabilities. Relations between the US and existing regimes have been strained over recent years, resulting in a lack of HN support agreements for incoming US forces.

c. The result is eitner poor or incomplete planning for the employment of US forces into the region. This makes it difficult to determine realistic engineer support requirements as: changing forces results in different engineer support for their operations, changing locations results in differing available HN assets to offset engineer support requirements, and also impacts on the amount or type of support needed (for example, changing from a built up area with a large amount of infrastructure, to a remote location can radically increase the need for engineer support to other units).

d. Lack of HN agreements does not allow the engineer planner the ability to decrement facility or manpower requirements in accordance with recognized support. Unavailable or outdated information on host nation infrastructure such as roads and raillines impacts calculation of engineer support to main lines of communication.

9. **ANALYTIC SUPPORT REQUIREMENTS.** The limitations on available data discussed in the previous paragraph are problems that can be tackled through diplomatic channels. However, the analysis community can play a major role in supplying the answers to two areas that are currently a void in the planning process: a Department of Defense (DoD) approved scenario and a means of estimating war damage.

a. **Scenario.** Data on expected scenario conditions under which US engineers will operate during combat is necessary to develop meaningful estimates of engineer work.

(1) FEBA movement rates and personnel or equipment losses due to threat advances for Army forces are normally determined through the play of a DA approved scenario. Both of these impact on the amount of engineer effort required and available to support Army forces as they move from staging areas forward, and then as they retrograde from the FCZ into the RCZ and possibly into the COMMZ. The maritime front offers its own unique generators of engineer tasks for enlarging existing ports and airfields as the US fleet moves into the region, as does the movement of Air Force units into primary, and if necessary, alternate air bases whose only existing facility may be the runway.

(2) Integrating these into a single DoD approved scenario that addresses the entire AO from eastern Turkey to Spain and Portugal has not been done for this region. In fact, it has not even been done for any of the individual services. ESC also found that there are no war games that serve this purpose. The scenarios and wargames that do exist address the war in Central Europe with a cursory look at the flanks. Those that do focus on the Southern flank are basically textual descriptions of force movements or sets of orders used in Southern Region exercises, and not based on any analytical modelling. The scenario ESC developed for use in this study is based on information provided in each of the services' OPLANs and supplemented with data from several other sources listed here:

(a) The primary reference used for the creation of the study scenario is "Exercise Plan for Exercise WINTEX-CIMEX 89".

(b) "WARGAME THRACE", prepared by the Strategy and Plans Directorate, US Army Concepts Analysis Agency (CAA), 1987.

(c) "Allied Forces South Seminar Wargame", prepared by the National Defense University, 1987.

(d) "Department of Defense, Defense Guidance, FY 1990 - 1994", 1987.

(e) "Global War Game 1988 (GWG-88)", Naval War College, 1988.

(f) "War in the Southwest TVD (SWTVD)", prepared by the Defense Intelligence Agency, 1985.

(g) "Conventional Force Capabilities in the Southern Region of Allied Command Europe", SHAPE Technical Center, 1986.

(h) "US Army Operational Readiness Analysis OMNIBUS-88", Department of the Army, 1988.

(i) "The Reception and Onward Movement in Europe (ROME) of Reinforcements and Resupply -- Southern Region", Institute for Defense Analysis, Alexandria, Va., Draft, 1989.

(j) "Concept of Maritime Operations Mediterranean Theater", US Naval Forces, Europe, May 1989.

(3) **Recommendation.** Development of a DoD scenario for the Southern Region based on approved models is the number one challenge to the analytic community.

(a) The model must address joint US operations and account for Allied force capability against a Soviet threat. It must also account for the role terrain plays as a force multiplier in areas such as Greece and eastern Turkey and the geographical dispersion of forces. Finally it needs to take a realistic look at a threat force that contains a high percentage of lesser capable WARSAW PACT aligned forces.

(b) Until an approved scenario is modeled and the results analyzed, requests based on current wartime planning not only for engineer support, but all combat, combat support, and combat service support will be questioned by higher levels in DoD. In addition, the ability of the services to justify existing or increased forces, future funding of US and NATO construction programs, prestockage of various classes of supplies, and support from host nations is doubtful. Justification for all these programs is tied to the ability to analytically defend wartime requirements

b. **Estimating War damage.** Repair or replacement of war damaged facilities is perceived to be a major consumer of engineer resources in any theater or region. This perception holds true not only for the FCZ and RCZ AOs, but also the COMMZ.

(1) A review of available models for use in this study found none that suited ESCs requirements. Most models developed to calculate war damage are limited to single sorties against single targets (or multiple targets within a single location such as an airbase). The models mainly stress damage caused by an air threat, and do not account for other threats, such as missiles or terrorist/covert/special operations units.

(2) The results of these models do not easily translate to an entire array of targets within a theater/region, and does not permit the accumulation of damage over the length of the scenario. Defining a likely threat becomes an exercise in diplomacy between the intelligence factions in DoD, Air Force, Army, and Navy. Much of the efforts to date have been focused on war damage at air bases, and have not expanded out to include ports, supply depots, roads, bridges, radar sites, and other critical facilities located in the COMMZ.

(3) **Recommendation.** The analytic community needs to devote effort to develop a war damage tool that provides analysis on a theater or region level.

(a) The threat should include a wide number of platforms that can be expected to inflict damage to rear area critical targets. The increased threat to rear facilities due to not only covert special operations, but also by local terrorists should be included in any future efforts. The vulnerability of rear targets to this type of threat can be easily verified by news stories of the last several years.

(b) The model should take into account not only the varying threats, but also a wider range of ground based targets. This range of targets should reflect the reality of joint operations in a theater/region in that damage to rear targets affect the ability of all services to operate in the region. For example, damage to ports not only affects the ability of the Army to offload and move combat forces into the theater, but also affects the ability of Naval forces to resupply forces, and the Air Force to offload the fuel needed to support its aircraft.

(c) A joint-approved threat needs to be established. This would provide all analysis agencies with a common basis to evaluate not only the engineer-related aspects of war damage, but the effect threat operations have all aspects of combat operations. This would include a joint list of targets and the priority of those targets within each theater/region, the type of threat platform expected to be used against a given target, and the most likely payload.

(d) Finally, the model must be able to portray threat operations against a given target over the course of an approved scenario. For example, an airfield would have X number of aircraft type one on day ten, while on day 20 Y number of aircraft type one and two would be targeted against that same airfield. This would provide the user with a compilation of damage over time given an approved attack profile.

KOREA BARRIER ALTERNATIVES

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1. PURPOSE. The Korea Barrier Alternatives (KBA) study assesses the adequacy of the existing barrier system protecting the Republic of Korea (ROK) from a north korean (nK) attack. It recommends modifications needed in that system due to changes in the nature of the nK threat, the present state of effectiveness of the existing barrier system, and the current concept of operation envisioned under the Combined Forces Command (CFC) operations plans.

2. SCOPE. The study examines the density and mix of the system of obstacles emplaced to block an attack across the demilitarized zone (DMZ) in Korea.

a. The existing barrier system and various barrier alternatives are evaluated to assess how well they support current CFC forces and plans. The study is based on available intelligence estimates of current nK counterbarrier capabilities. To ensure the barrier improvements recommended will not become obsolete by changes that nK forces could easily make, we also assessed counterbarrier systems likely to be acquired by nK forces in the near future.

b. The study looks at ways to improve the effectiveness of the present barrier system, considering variations in the density and mix of current components of CFC's barrier system.

c. The study considers new technology systems only if they are expected to be in production before 1995. In order to keep the study focused on quickly implementable solutions, ESC did not consider exotic new technology that would require long research and development programs.

3. REPORT ORGANIZATION. The results of the Korea Barrier Alternative Study will be published in a main report and two monographs. The main report, *Korea Barrier Alternatives*, has been given to the study advisor group (SAG), in draft form, for their review and comment.[1] The two monographs which support the study, *The Strategic Performance of Defensive Barriers* and *The nK Counterbarrier Threat*, were published separately[2,3]. This paper present an unclassified summary of the methodology used to evaluates the obstacles in the

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[1] *Korea Barrier Alternatives* (SECRET-RELROK), DRAFT (Engineer Studies Center, August 1989).

[2] *The Strategic Performance of Defensive Barriers* (U), (Engineer Studies Center, August 1987).

[3] *The north Korean Counterbarrier Threat* (SECRET-RELROK), (Engineer Studies Center, June 1989).

Approved for public release;
distribution is unlimited.

Korea barrier system (KBS). Release authority for these documents rest with CFC, as the study sponsor.[4]

4. **MODELING ANALYSIS.** In February 1988, the US Army Concepts Analysis Agency (CAA) agreed to support the Korea Barrier Alternatives study.[5] CAA's analysis used a computer simulation to examine the effect of barriers under conditions similar to those that exist on the Korea peninsula. It looked at a corps-sized nK attack against a division-sized ROK defender (approximately a 3:1 force ratio), under various terrain and barrier conditions. A more detailed description of the war game and model results is being published separately.[6] The simulation used by CAA was the Combat Sample Generator (COSAGE) model.

a. **Approach.** To evaluate obstacle effectiveness ESC sought to observe obstacle effects over a range of conditions and obstacle plans. The major problem, however, was that ESC was limited to comparably few scenarios relative to the large number of variables (or factors) that were involved. To design a set of model cases covering as wide a range of conditions as possible, three scenario groups were developed and labeled as reference, base, and alternative cases. Reference cases had no obstacles and were control cases in the sense that they measured battle outcome without any obstacle delay or attrition. Base cases introduced obstacle distributions derived from division barrier plans drawn from the KBS database. Alternative cases were modifications to base case obstacle plans that were used to test the effects of changes in obstacle density and mix. The actual changes to the obstacle plan reflected in the alternative cases were dependent on the range of obstacle densities and observed results in comparable reference and base cases. The results of the cases were then analyzed with respect to several performance measures (losses and attacker movement). The process is illustrated in Figure 1.

b. **Data.** As a data-driven model, COSAGE requires substantial input. Fortunately, ESC was not required to construct the many data files necessary to define nK-ROK engagements. CAA had compiled much of what was needed in performing its own studies of materiel requirements for a Korean war scenario. ESC worked closely with CAA to develop the additional data required for the KBA study, particularly the obstacle and barrier definitions.

c. **Scenario.** The ROK defense of the demilitarized zone (DMZ) in Korea simulates a stylized ROK Army division in a prepared defense against three north Korean stylized divisions. To portray the channelized corridors that are prevalent along the Korean DMZ the general concept of operations used for ABAKUS depicts the ROK Army Division deployed in a three corridor defense. The attacking north Korean forces in the central and western corridors represent holding actions. These actions are designed to prevent ROK

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[4]Headquarters, ROK-US Combined Forces Command, ATTN: MAJ Anderson, APO San Francisco 96301-0028

[5]CAA categorized the support as a study effort and is documented in the ABAKUS report.

[6]Analysis of Barrier Systems Alternatives in Korea for ROK/US (ABAKUS), (US Army Concepts Analysis Agency, to be published October-November 1989).

BARRIER ANALYSIS PROCESS

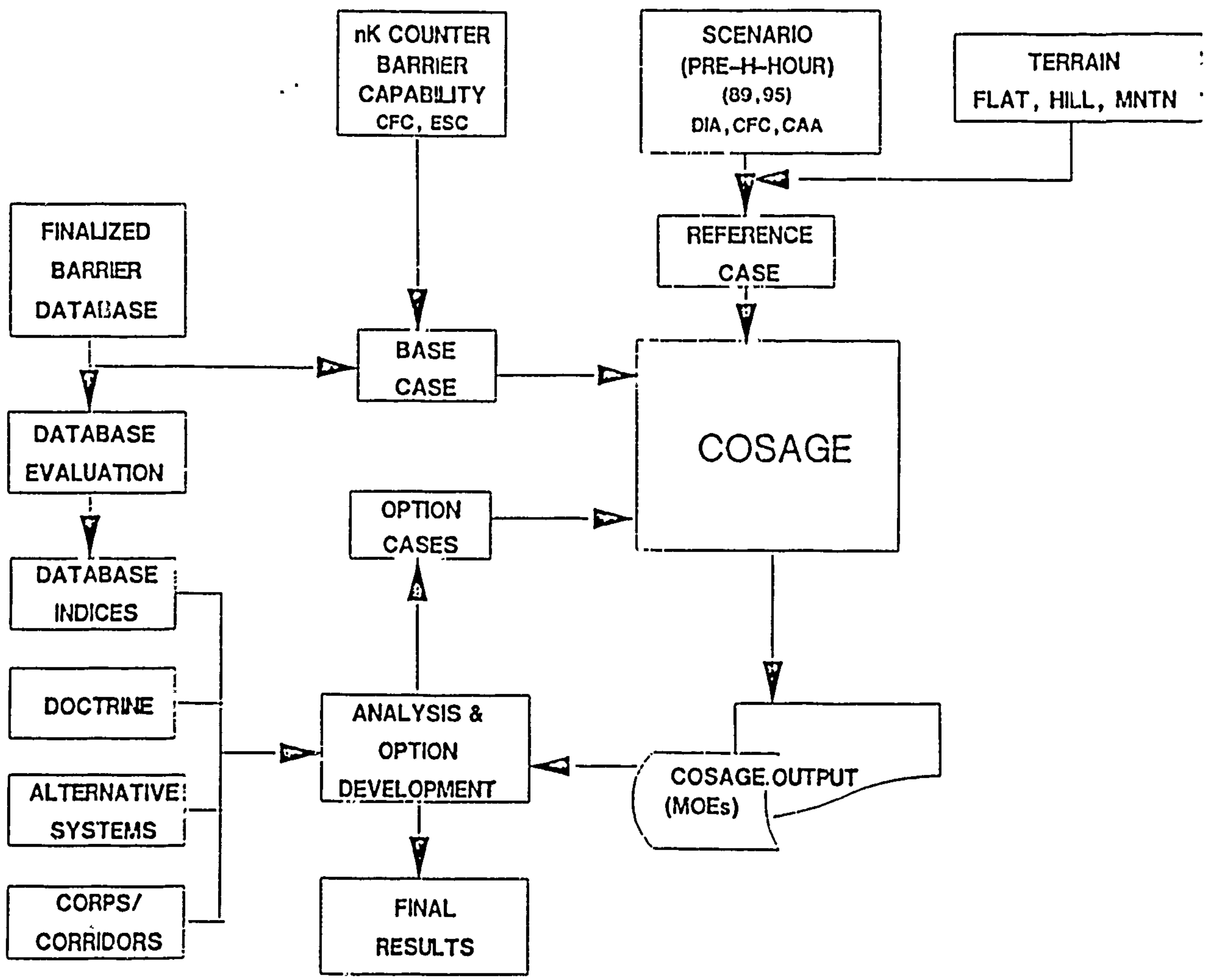

Figure 1.

defensive forces from reinforcing the ROK forces facing the nK main attack in the eastern-most corridor. Furthermore, no interaction is permitted between forces in adjacent corridors. The flexibility of movement orders for individual attacking units within the simulation permitted ceasing the attack shortly after contact in the holding corridors, while extending the advance of the attacking forces in the main attack corridors.

d. **Data Sources.** The threat and scenario data used in the analysis are derived largely from the Pre-H Hour Study[7] and CFC OPLAN 5027.[8] Other determinants of scenario performance are the orders that direct forces within a simulation. In COSAGE, terrain influence is derived from line-of-sight and movement data. Roads, mountains, rivers, and urban areas are not explicitly identified in COSAGE. However, the movement orders given to forces are also a means to account for terrain differences. The use of the different terrain features of COSAGE required minor modifications to the movement orders for the attacking forces. The originally used mountainous terrain permitted considerably slower movement for vehicular and personnel traffic than hilly/rolling or flat terrain. The COSAGE input data that controls the speed of movement as a function of terrain type allow for mountainous terrain movement speed to be 60 percent of the movement speed of the COSAGE unit when the unit is in hilly/rolling terrain. Additionally, the movement speed of units on flat terrain was 20 percent faster than units in hill/rolling terrain.

e. **Forces.** COSAGE defines units down to company and even platoon level. A unit definition will define troop and weapon system composition. Since COSAGE results were used for engagements having different organizations, units are "stylized." These organizations represent composite profiles, or an "average" unit. Stylized units may not duplicate the Table of Organization and Equipment (TOE) of any particular unit, but should reasonably approximate a typical unit based on the best available information for both friendly and threat forces.

f. **Obstacle representation.** ESC's primary concern was obstacle representation. Because obstacles and engineer play are not central concerns of COSAGE, ESC reviewed how the model simulated obstacles and their effects to determine how well COSAGE could support this study. That review identified areas of model logic and input data which were improved for this study. One significant change was an expansion of obstacle types that could be defined. Previously, COSAGE played only minefields and a barrier obstacle which was really a non-killing, minefield variant. These types were hardwired into the model. At ESC's request, COSAGE was changed to permit a user to define as

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[7]North Korean Pre-H-Hour Attack Scenario: A Combined Study (U), DDB-2600-1142-87, (Defense Intelligence Agency, Feb 1987).

[8]Ground Component Command Operations Plan 5027 (U), GCC OPLAN 5027 (SECRET-ROKUS), January 1988.

many obstacle types as were needed.[9] For KBA, the following obstacle types were defined: minefield, road crater, tank ditch, wire, road drop, wall, rock slide, and dragon's teeth. Obstacles in COSAGE have two primary attributes--delay and attrition. All obstacles were given delay time parameters, but only minefields were given the ability to directly cause attrition.

(1) Delay times. The increase in the number of different obstacle types played in COSAGE required ESC to provide reasonable delay time ranges. COSAGE calculates delay times by sampling from a uniform distribution, where minimum and maximum delays are specified by the user. Obtaining estimates of times required to conduct the actual breaching of specific obstacles under various conditions is difficult enough, much less estimates of the total delay imposed on a unit from the time it first detects an obstacle to the time it has completely crossed the obstacle and is ready to resume its advance. However, it is these total delay times that are required as input to COSAGE. ESC ultimately found that because of the lack of accepted delay factors, and the particular requirements of COSAGE, that it had to develop its own delay time estimates that reflect CFC obstacle characteristics and nk counterbarrier capability. The resulting delay times are summarized in Figure 2.

COSAGE MODEL DELAY TIMES (minutes)					
		TYPE FORCE			
		MECHANIZED		DISMOUNTED	
OBSTACLE TYPE	CONDITION	MIN	MAX	MIN	MAX
1. Minefield	known unknown	35 60	205 275	40 55	220 285
2. Road Crater	known unknown	25 60	50 90	5 15	10 20
3. Tank Ditch	known unknown	25 60	50 100	5 15	10 20
4. Wire	known unknown	5 15	30 40	20 30	30 55
5. Road Drop	known unknown	60 75	180 255	15 25	20 30
6. Wall	known unknown	60 75	160 210	20 25	25 30
7. Rock Slide	known unknown	60 75	180 250	15 25	20 30
8. Dragon's Teeth	known unknown	60 75	135 200	5 15	10 20

Figure 2.

[9]Warner, John, "Changes to COSAGE for the ABAKUS Study," COSAGE Note 9 (CAA, August 1988).

(2) Attrition factors. The expected attrition caused by minefields is based on tables provided to CAA by the US Army Materiel Systems Analysis Activity (AMSAA).[10] AMSAA produces this data for CAA and other study agencies as the US Army's authoritative source of weapon systems parameters for use in combat simulations. Despite performing an extensive literature search, ESC could find no better, or more authoritative, source for minefield attrition than the AMSAA data being used by CAA. Figure 3 shows that for all classes of weapons and personnel, the casualties for each minefield encounter will fall within the range of zero to five.

g. **Obstacle plan development.** Input preparation for ABAKUS was shared by ESC and CAA. By far the largest task was the effort required to define the barrier plan (e.g. obstacle mix and locations) that would be used within COSAGE for each of the base and alternative cases that were gamed. Base case plans were constructed by adapting and modifying representative division sectors. The sectors selected were chosen to cover a wide variety of different conditions of threat, terrain, phase line position, and sector width.

COSAGE MINEFIELD ATTRITION RANGES				
Victim Type	Minefield		FASCAM	
	min	max	min	max
Troops	0	5	0	5
Lt. Armor	0	3	0	2
Armor	0	3	0	2
Lt Vehicle	0	0	0	3
Crew Weapon	0	0	0	1

Figure 3.

[10] Barrier Warfare Handbook, Handbook Series, Series G, Number 3, Volume 1, (US Army Materiel Systems Analysis Activity, Aberdeen Proving Ground, MD, 1981).

5. **OBSTACLE ANALYSIS PROCEDURE.** In addition to the modeling analysis done using COSAGE ESC conducted a detailed obstacle analysis of each corps and front line division sector in the Korea barrier system, Figure 4 shows the five-step methodology used to conduct this detailed obstacle analysis.

a. **Step One - Actual Obstacle Density Index.** Not all obstacles are equal in their relative effectiveness. Some obstacles delay only vehicular traffic; others are effective only against personnel. For a detailed density analysis this study separates obstacles into four general categories: minefield, point, wire, and non-minefield/non-wire linear obstacles (henceforth called "linear obstacles"). Minefield, wire, and linear targets are divided into 100 meter segments (e.g., a target 1,000 meters long equals 10 obstacles). Point targets each count as one obstacle. ESC standardized the relative effectiveness of different obstacles by considering the delaying ability of each obstacle, it's effectiveness against either personnel or vehicles, and it's ability to cause attrition (minefields only). Figure 5 summarizes these relative effectiveness values. Once the relative effectiveness values of different obstacles have been determined you can compute the *actual density index*, a measure of weighted obstacle density per square kilometer. To find the total obstacle density index, add the relative obstacle values for each division zone and then divide by the area of that zone. For example, a zone containing 1000 meters of minefield targets, 5 point targets and 2000 meters of wire targets in a zone of 100 square kilometers has a .4 density index. To calculate this, multiply the relative effectiveness value of each obstacle (from Figure D-2) by the number of obstacles (Remember, "one" linear target is 100 meters, therefore you must divide the overall length of obstacles such as minefields -- in this case, 1000 meters -- by 100 to arrive at the number of obstacles.) Add the resulting products for all obstacles. Divide by the zone area as shown:

10 minefield obstacles x 2.5 relative effectiveness value	= 25
5 point obstacles x 1.0 relative effectiveness value	= 5
20 wire obstacles x .5 relative effectiveness value	= 10
	40
40 equivalent obstacles/100 sq km = .4 obstacle density index	

The *obstacle density index* combines two separate sets of data which must be computed separately: the *wire density index* and the *total obstacle density index* (which includes all obstacles). This data will be used to conduct the obstacle mix analysis in step four.

b. **Step Two - Desired Obstacle Density Index.** In this study, ESC developed the *desired obstacle density index* to consider: the tactical concept of minimizing ground loss (i.e., very strong first line defenses); terrain as reflected in cross country mobility (CCM) for mechanized forces; and possible counterattacks, should the enemy penetrate initial defense lines. To determine desired obstacle density, ESC first developed average density indices based on existing densities for each division across the CFC front. The indices for existing densities provided excellent norms by which to evaluate the density of the existing system since they were based on actual capabilities and tactical needs. ESC analysts computed these indices using information from the 1989 database and the methodology described in step one above. ESC then used the density averages to develop *desired obstacle density index* values. Once a division's *desired* density index has been identified, it can be compared to the *actual* obstacle density index.

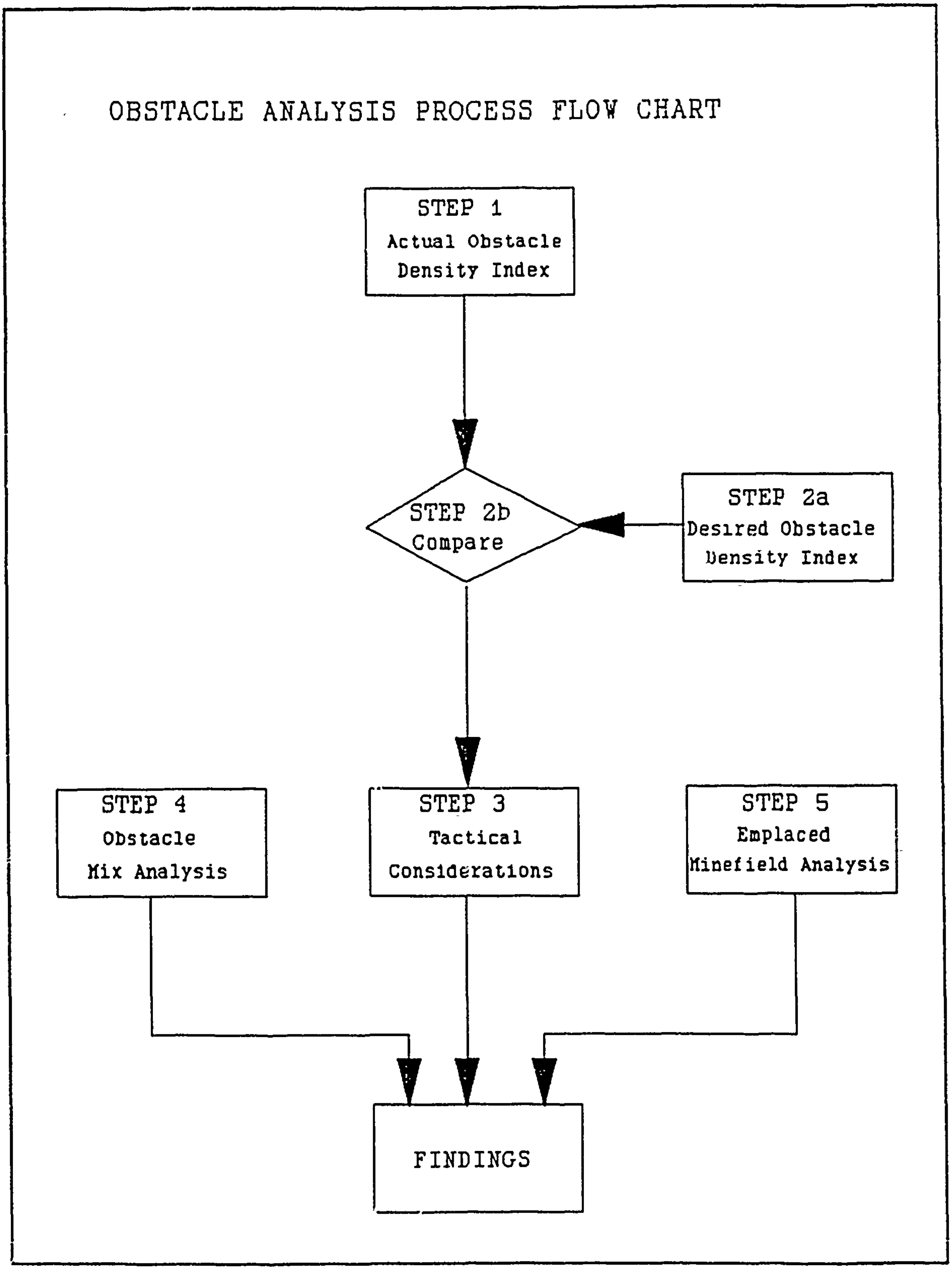
OBSTACLE ANALYSIS PROCESS FLOW CHART
STEP 1
Actual Obstacle
Density Index
STEP 2b
Compare
STEP 2a
Desired Obstacle
Density Index
STEP 4
Obstacle
Mix Analysis
STEP 3
Tactical
Considerations
STEP 5
Emplaced
Minefield Analysis
FINDINGS

Figure 4

RELATIVE OBSTACLE VALUES		
TYPE OBSTACLE	DIMENSION	RELATIVE VALUE
Minefield	100 meters	2.5
Point	each	1.0
Wire	100 meters	0.5
Linear (non-wire/non-mine)	100 meters	1.0

Figure 5

c. **Step Three - Tactical Considerations.** After comparing *actual* to *desired* obstacle density index, the next step is to consider tactical conditions. Even if the actual density meets or exceeds the desired density, these conditions should be considered to examine tactical planning. If a division's actual density index is less than the desired index, an in-depth analysis should be conducted to determine why. Such areas as mutual support of terrain and obstacles, avenues of approach, employment in depth, obstacle free areas and obstacle placement should be included in any analysis. When conducting the analysis, the primary avenues of approach should be examined in greater depth than secondary avenues.

d. **Step Four - Obstacle Mix Analysis.** "Obstacle mix" refers to the choice of a variety of obstacles based on terrain considerations, threat attack forces and their counterobstacle capability, and available resources and time for installing targets. When evaluating an obstacle plan, considering these factors results in tradeoffs and alternative solutions. There are no simple answers to obstacle mix questions. Determining an appropriate obstacle mix must be done by applying military judgment, general guidelines, and by comparing the various CFC units.

(1) In this study, the guidelines for determining obstacle mix are as follows:

(a) Open terrain dictates a need for linear obstacles such as minefields, walls, anti-tank ditches, dragon's teeth, or wire.

(b) Less trafficable terrain dictates a need for point obstacles such as slides, road craters, road drops, bridge demolitions, or point minefields.

(c) A variety of obstacles helps complicate and confuse enemy counterobstacle operations and consume counterobstacle resources.

(d) When time is limited, use obstacles which can be emplaced quickly.

(e) Install constructed obstacles, such as defensive walls, road drops, dragon's teeth, and canals, during peacetime as circumstances permit.

(2) Evaluating obstacle mix includes comparing the percentage of point-to-total obstacles and percentage of minefields-to-total linear obstacles. The actual balance depends on aspects such as terrain and threat. Doctrinal considerations, as well as the obstacle balance recommended in the *Engineer Assessment Korea*[11] study completed in 1986, is considered as is the averages for obstacle mix among the different CFC units.

(3) ESC developed specific guidelines for evaluating the mix of wire obstacles by considering the overall prevalence of wire in the obstacle system (Based on information in the KBS database) and threat and doctrinal considerations. Recommended wire prevalence was based upon the phase line location of the obstacle and the CCM, both of which directly impact the threat force structure.

e. **Step Five - Emplaced Minefield Analysis.** Using the findings from similar studies done by the Army Materiel Systems Analysis Agency (AMSAA), the Republic of Korea Army (ROKA), and Picatinny Arsenal, this step determines the expected reliability of emplaced minefields on a division by division basis.

6. **CONCLUSIONS AND RECOMMENDATIONS.** The following paragraphs describe some of the general conclusions and recommendations that can be presented in this unclassified paper. The results of the detailed obstacle density and mix analysis deal with specific unit sectors and sensitive elements of the CFC OPLAN. Therefore, the sponsor determined that this information was not only classified, but could only be released within ROK and US channels.

a. **Overall Conclusions.** Considering obstacle effectiveness in a macro sense, the overall contribution of obstacles in this analysis lead ESC to the following conclusions:

(1) Obstacles reduce the attacker's advance and tempo. Natural obstacles (i.e., terrain) certainly reduce attacker advance. The addition of obstacles further limits the advance. Slowing the advance also seems to slow the tempo of the battle as reflected by reduced casualties.

(2) Attacker losses increase in some categories. Results showed that combat vehicle losses, in particular, increase in the face of barriers that incorporate minefields. It was also observed that the supposed synergy of linking minefields with direct fire defenders could not be demonstrated in this model analysis (with the possible exception of one case). Minefields killed combat vehicles, but in most cases these kills did not contribute to an increase in total kills because other weapon systems killed fewer vehicles. This is interpreted as a limitation of the model and the fact that obstacle

[11] *Engineer Assessment, Korea: Forward Combat Zone Analysis*, (ESC, July 1986), p. 44.

placement could not be coordinated with initial unit dispositions to ensure that obstacles were effectively covered by direct and indirect fire.

(3) Defender losses declined. While the increases did not materialize in attacker losses, defender survivability increased. Losses in all major categories declined with the introduction of obstacles. Again the reduction in the tempo of the battle may contribute to this result. As the battle slows and movement is less, there may be fewer engagements as well.

b. Overall recommendations. The detailed classified recommendations provided to CFC are derived from the two following key recommendations:

(1) Priority Barrier Improvements. CFC should continue a vigorous program to maintain and upgrade the barrier system. To focus this ongoing program on the most critical areas ESC recommended an upgrading effort divided into three priority groups, with Group A the highest priority and Group C the lowest priority. Group A includes those division zones that have high-priority shortcomings in both density shortfall and emplaced minefields; Group B includes those division zones where density shortfalls are a high priority and emplaced minefield shortcomings are a moderate priority; and Group C includes those division zones where either density shortfall or emplaced minefields have a high priority.

(2) KBS Database. The KBS database should be used as a tool to plan and monitor the progress of the upgrade program developed as a result of this study. However, before the database can be used in this way the consistency, and coverage of the database must be improved. The most important area requiring improvement is the need to adhere to a consistent set of coding conventions across all sectors. Once improved, the database will be a much more useful tool for all planners, from division staffs to CFC headquarters.

COST SIMULATION MODEL FOR FACILITY REPLACEMENT POLICY

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ABSTRACT:

Three cost simulation models have been developed and applied experimentally as part of a continuing effort to improve techniques for managing Army real property. The models consider a facility as an assembly of independent components, of which some are replaceable and others are nonreplaceable.

A component is replaced at the time of failure which is considered as an epoch of maintenance and repair (M&R) for a facility. The cost of component replacement was estimated by its original construction cost, and this figure was adjusted upward to the original construction cost to account for the additional labor and possible damage caused to other, adjacent components. The M&R cost of a facility was considered to be the result of successive failures of replaceable components. By applying these factors, three simulation models were developed to successively: (1) estimate M&R cost by the facility's age, (2) evaluate replacement strategies, and (3) predict future cost requirements of the facility.

INTRODUCTION:

Due to the variety of design, material composition, and other external factors affecting building performance, prediction of the service life for a building or its components is seldom unanimous. This situation has caused confusion to the point that all research into facility management has lost its generality and invited common-sense criticisms of simulation models for practical application. Another problem in this research field is that past facility investment in the U.S. Army fluctuated greatly, due in part to changes in defense policy.

Despite these circumstances, a facility management decision-maker is always required to make relatively knowledgeable decisions. The research to date into real property management has made significant gains such as identifying M&R funding requirements, analyzing life-cycle costs of facilities[1], and constructing a framework for building research[2]. Simplifying the actual decision environment and sacrificing certain specifics are sometimes unavoidable. However, appropriate simulation models can maximize the realism in making decisions on facility renewal/replacement.

SIMULATION MODELS

Three simulation models that have identical basic structures, with minor modifications, evolved in sequence. Figure 1 shows the model development procedures. From this approach, a basic framework was formed.

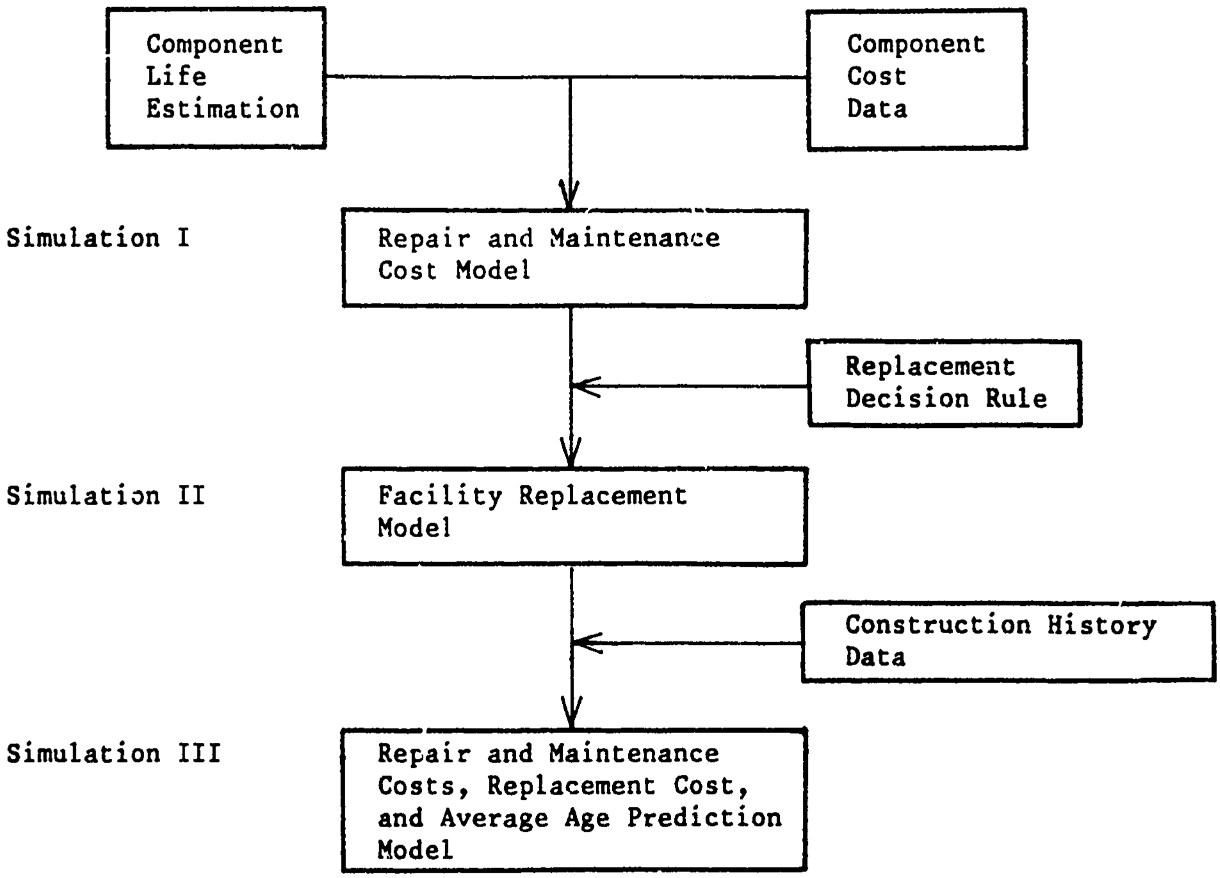

Figure 1. Model development procedure.

Framework
A facility consists of replaceable and nonreplaceable components. The lifespans of replaceable components may be shorter than the life of the facility whereas those of nonreplaceable components may be as long as the facility's life. As an example, foundations and framing might be classified as nonreplaceable components, with roofing, doors, and windows considered replaceable components. For simplicity, the costs of minor repair and routine maintenance are ignored; the replacement of a replaceable component is assumed to be a major cause of cost incurrence for facility M&R. In other words, the history of M&R costs for a facility is assumed merely as a record of replacement cost of the individual replaceable components. Hence, the model requires two kinds of basic data: life length and replacement cost for each component.

Component Life
The time it takes a living thing or piece of equipment to fail is probabilistic by nature. Even describing the state of failure is ambiguous and

sometimes very subjective. Hence, defining the failure state of components is useful in describing failure of the overall facility. Since minor repair requirements are not considered in this study, the scope of the problem can be narrowed by adopting the following definition: "The state of failure of a component is the state for which the long-run cost efficiency of a facility is best achieved by replacing the component."

The lifetime of a component was estimated in three ways: (t_ℓ) longest (or optimistic) life, (t_m) most likely life, and (t_s) shortest (or pessimistic) life. This three-way life estimation is a basis for determining a particular shape of time-failure curve (Weibull distribution) for a component.

<u>Weibull Distribution</u>

The empirical Weibull distribution appears to fit a large number of failure characteristics for equipment[3]. Specific applications of this distribution function for modeling construction material can be found in [4] and [5].

The probability density function of the Weibull distribution is:

$$f(t) = \begin{cases} \frac{\eta}{\sigma}\left(\frac{t-\gamma}{\sigma}\right)^{\eta-1} \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right], & t \geq \gamma,\ \sigma > 0,\ \eta > 0 \\ 0 & \text{elsewhere} \end{cases} \qquad \text{[Eq 1]}$$

where

- σ = scale parameter or a component i
- η = shape parameter or a component i
- γ = location of the origin of a component i.

The cumulative Weibull distribution is:

$$F(t) = \int_0^t \frac{\eta}{\sigma}\left(\frac{y-\gamma}{\sigma}\right)^{\eta-1} \exp\left[-\left(\frac{y-\gamma}{\sigma}\right)^{\eta}\right]dy = 1 - \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right],\ t \geq \gamma \qquad \text{[Eq 2]}$$

<u>Parameter Estimation of Weibull Distribution</u>

It can be shown that: given t_ℓ, t_m, and t_s for each component, σ, η, and γ can be calculated without loss of generality be making $\gamma = 0$ and substituting in the following equations.

$$\eta \mathrm{Ln} t_m - \eta \mathrm{Ln}\sigma = \mathrm{Ln}(\eta-1) - \mathrm{Ln}\eta \qquad \text{[Eq 3]}$$

$$\eta \mathrm{Ln} t_\ell - \eta \mathrm{Ln}\sigma = \mathrm{Ln}2 + \mathrm{Ln}(\mathrm{Ln}10) \qquad \text{[Eq 4]}$$

<u>Generation of a Component's Replacement Cycle</u>

Let U = a pseudorandom number. For the Weibull distribution function, let:

$$F(t) = 1 - \exp\left[-\left(\frac{t-\gamma}{\sigma}\right)^{\eta}\right] = U \qquad \text{[Eq 5]}$$

or:

$$-\left(\frac{t-\gamma}{\sigma}\right)^{\eta} = \mathrm{Ln}(1-U) \qquad \text{[Eq 6]}$$

Therefore, the life of a component is:

$$t = \gamma + \sigma \, [-\text{Ln } (t-U)]^{1/n} \qquad \text{[Eq 7]}$$

Cost Estimation of Component Replacement
New construction cost of a facility is used as a basis for estimating the replacement cost of a component. The new construction cost of a component is adjusted by considering additional labor and/or possible damage to adjacent components during repair activities. For example, painting an old facility might require scraping the old paint off; or, replacing the duct system for heating and air-conditioning may damage the floor or ceiling.

Generation of a Component's Replacement Cost
A ±10 percent variation is allowed in the replacement cost of a component. The component replacement cost varies uniformly within this range.

Let: U = a pseudorandom number

R = average replacement cost of a component i

Then, the replacement cost of a component i is:

$$C = 0.9R + 0.2R \times U$$

Facility Replacement Criteria: Relative Repair Cost
A component of a facility might be functioning poorly or deteriorating rapidly in the later stages of its life before it actually fails. Such a component is defined as a "marginal component." A period of state as a marginal component is termed the "marginal period" of a component. The length of a marginal period for each individual component is assumed to be the last quarter of its life; i.e., the last 25 percent of its life length.

A facility is replaced if there are many marginal components and replacement of those components would require a high expenditure. As a criterion of facility replacement, the concept of relative repair cost can be introduced. "Relative repair cost (RRC)" of a facility is the ratio between repair cost and restored value. "Restored value" is a current (market) value when marginal components are completely repaired. Thus:

$$RRC = \frac{\text{Repair cost of marginal components}}{\text{Restored value}} \qquad \text{[Eq 8]}$$

In considering the replacement of operational equipment of a production facility, the M&R cost of an object usually is not compared with its market value. The basic difference between a production facility and a real property facility in a replacement decision might be the conceptual difference between use value and exchange value. A production facility is a means to produce a certain end-product. Since the purpose of a production facility is not for exchange but for production, the exchange value of the facility has no meaning. As long as the output maintains required objective quality standards, use value of a facility remains the same. Hence, M&R and new facility investment costs are adequate for determining replacement. On the other hand, a real property facility is not only an end-product that should satisfy various needs of a user, but also an exchangeable product as are other commodities that can be sold on the market. The effect of an activity given to the facility should be measured by the resulting gain or loss in exchange value.

If the relative repair cost sum of a facility exceeds a critical number (CR), the facility is replaced at the time when the first failed component is found among the marginal components. Otherwise, a component is replaced individually at the time of its failure.

Relative Repair Cost Measure: Implication as a Replacement Criterion

When a production facility or real property facility is replaced, the following relationship should hold at the time of replacement:

$$\begin{array}{c}\text{Immediate repair}\\ \text{cost savings by}\\ \text{replacement}\end{array} + \begin{array}{c}\text{Future repair}\\ \text{cost savings by}\\ \text{replacement}\end{array} + \begin{array}{c}\text{Value difference}\\ \text{from new facility}\\ \text{to current facility}\end{array} \geq \begin{array}{c}\text{New}\\ \text{facility}\\ \text{cost}\end{array}$$

As was mentioned earlier, the value of a production facility might be measured by its use value. There is no value difference between a new production facility and the current one in the above relationship since the use values of both facilities are considered the same. For a real property facility, the value might be measured by its exchange (i.e., market) value. Hence, the third term in the above relationship:

$$\begin{array}{c}\text{Value difference}\\ \text{from new facility}\\ \text{to current facility}\end{array} = \begin{array}{c}\text{New facility}\\ \text{market value}\end{array} - \begin{array}{c}\text{Current facility}\\ \text{market value}\end{array}$$

If it is assumed that market value of a new facility is equal to the cost of the facility, the following relationship holds for the replacement of a real property facility:

$$\begin{array}{c}\text{Immediate repair}\\ \text{cost savings}\\ \text{by replacement}\end{array} + \begin{array}{c}\text{Future repair}\\ \text{cost savings}\\ \text{by replacement}\end{array} \geq \begin{array}{c}\text{Current facility}\\ \text{market value}\end{array}$$

Dividing the left-side terms by the right-side term above:

$$\begin{array}{c}\text{Immediate relative}\\ \text{repair cost savings}\\ \text{by replacement}\end{array} + \frac{\text{Future repair cost savings by replacement}}{\text{Current facility market value}} \geq 1$$

The first term in the above relationship was applied as the replacement criterion in this report. Since the relative repair cost measure compares repair cost with the market value of a facility, the benefit of adopting this measure as a replacement criterion is that it can indirectly reflect functionality and design, as well as physical condition, of a facility.

Long-Run Average Relative Facility Cost

Long-Run Average Facility Cost (LAFC) is defined as an annual average cost of a facility for its construction and M&R during the service life. Thus:

$$\text{LAFC} = (\text{Probability of life length}) \times \frac{(\text{Lifetime total repair cost} + \text{construction cost})}{(\text{Life length})}$$

A similar definition can be introduced by substituting repair cost with relative repair cost (or long-run average relative facility cost--LARFC) as follows:

$$(\text{LARFC}) = (\text{Probability of life length}) \times \frac{(\text{Lifetime total relative repair cost} + 1)}{(\text{Life length})}$$

Relative repair cost might implicitly consider the qualitative aspect of a facility. In this study, LARFC was applied as an optimal criterion for evaluating replacement decision rules.

Simulation Model I: M&R Cost Model

The purpose of the first simulation model is to investigate the behavior of M&R costs of a group of facilities in a facility investment category. A facility is considered to be a set of replaceable and nonreplaceable components. The failure of replaceable components is the cause of M&R costs. The failure of a component is generated by a Weibull random-number generator and the M&R cost is obtained by a uniform random-number generator. Inputs to the simulation are three-way life estimation data and construction cost data of each component. Simulation model output is the ratio of the annual average M&R cost to the replacement cost of a facility in percent.

Simulation Model II: Replacement Decision Model

The purpose of this model is to examine the aggregate cost of facilities' M&R and replacement over the long run by adopting a certain replacement decision value. Several different relative repair cost criteria are compared.

Inputs to the model are the same as in simulation model I. Outputs of the simulation are the probability of facility replacement by age, expected life of a facility, and ratio of the long-run annual average cost to the replacement cost of a facility for the respective replacement decision rule. Relative repair cost criteria for replacement decisions are examined. Absolute repair cost criteria, which are measured as a percentage of the replacement cost of a facility, are also shown as a reference to the relative repair cost criteria.

Simulation Model III: Facility Management Cost Prediction Model

An organization's inventory of facilities has a certain profile in terms of construction year and spatial quantity. Simulation model III was developed to predict the future cost trends of M&R and facility replacement using realistic inventory data.

A replacement decision rule is specified as an input along with the inputs of simulation I for the run of this model. Outputs of the model are the facility management cost and the average age of facilities in future years.

APPLICATION AND RESULTS

The simulation models developed implicitly assume that facilities are alike in terms of their components' lives and construction costs. However, this assumption might be too risky if the model is applied without discretion to all categories of building facilities.

As an example of implementing the models, the family housing category was chosen. Family housing recently received one-quarter of the Army's facilities management budget. To run simulation models I and II, two sets of data are needed: (1) three-way life estimation of components and (2) construction costs of components. Simulation III requires data sets 1 and 2 above, along with the inventory record of family housing by construction years and spatial quantity to predict future family housing management costs.

Simulation Model I Results

M&R cost was measured as a percentage of the facility's net replacement cost. Net replacement cost of a facility is the construction cost of the facility, excluding the cost of site work and contractor's overhead.

After heavy repair around age 55, the M&R cost drops and begins a new repair cycle. This result implies that adopting average age as an independent variable might be erroneous for estimating annual M&R cost requirements. The linear expression of M&R cost by age might be valid at best within the interval cf a major repair cycle.

Simulation Model II Results

Relative repair cost is a percentage cost of M&R over the market value of a facility. As a proxy of the market value, the restored value was adopted; this value is the worth of a facility with no marginal components at all.

No depreciation of a replaceable component was considered as long as the component was not marginal. Complete linear depreciation was assumed for the nonreplaceable components up to 75 years of age of a facility. Hence, the restored value is the net replacement cost less depreciation. The 75-year depreciation period was chosen subjectively as a compromise between housing service lives of 60 years and 88 years.

If there are several marginal components and the sum of the relative cost exceeds a certain limit, the facility is replaced at the time when the first component failure is observed among the marginal components. This model demonstrates that adopting a low relative repair cost (RRC) sum as a replacement decision criterion recommends earlier replacement of a facility than adopting a high relative repair cost sum criterion.

For a given maximum facility life, the LARFC is estimated for respective replacement criteria. For the maximum life of 100 to 150 years, the 60 percent of relative repair cost criterion is obtained as the long-run optimal value.

Simulation Model III Results

As was mentioned earlier, adopting the average age of facilities as a variable might be insufficient to estimate the M&R costs due to the fluctuation of these costs. In this simulation model, facility inventory data by construction year and spatial quantity were obtained and used as additional input for the simulation.

Simulation model III generates the inventory profile and predicts the M&R and replacement costs up to the year 2100. The average age of family housing is also predicted. To run the simulation, a replacement criterion must be input at the beginning of the program.

Since the replacement criterion of a low RRC sum requires early replacement of facilities, high facility cost due to replacement is shown in year 2005 by the 50 percent RRC replacement criterion. Using the 60 percent criterion defers replacement and reaches a peak around 2050. Facility cost fluctuates very much in the future because family housing construction was not spread well enough to reduce the cost fluctuation.

For the 60 percent RRC criterion, a continuous increase in replacement cost and facility cost requirement is observed until the year 2010. After the temporary decline, both costs peak around 2050. However, M&R cost remains quite stable--around a 2 percent level of total replacement cost. High replacement costs are compensated by the reduction in M&R cost. This result implies that M&R cost and replacement cost requirements might be considered together.

CONCLUSIONS AND RECOMMENDATIONS:

1. M&R cost should be considered along with the facility replacement policy--especially in budgeting--since the frequency of replacement affects M&R costs.

2. The facility inventory profile detailed in construction year and spatial quantity might be a relevant input to project the future M&R and replacement cost requirements since using average age of facilities as an independent variable appears inadequate to represent the fluctuating behavior of M&R cost.

3. Adopting average age of facilities as a managerial goal should be reviewed since average age is merely a result of a replacement policy, and not a cause of the policy. Moreover, due to the heavy construction during a certain period (e.g., 1950s and 1960s), family housing requires too high a replacement cost which might not be spread over a long enough interval to smooth the annual budget requirement if average age is applied as a replacement goal.

4. The relative repair cost measure might be a very useful criterion for facility replacement decision-making. RRC can indirectly reflect

functionality and design as well as physical condition of a facility by considering its market value as a dimension of effectiveness of the replacement decision.

5. To assess the models' applicability to Army facilities other than family housing, similar investigations should be performed, replacing this facility type with, for example, barracks, administrative buildings, and training facilities. If the models prove successful, they should be refined and suggested as alternatives to existing prediction methods.

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Selected Methodology for Cost and Quantity Estimation of Alternate Army Structures

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This paper has the following two subjects:

1. Estimating the cost and quantities of alternate future structures
2. Planning of weapon systems, other major equipment and ammunition to be procured/phased out to arrive at a planned future structure

1.1 The KOSMOS DATA BANK as a Basis for the Cost Estimations

KOSMOS contains for each subunit (e.g. tank platoon), unit (e.g.tank company), cost center (e.g. tank battalion) and cost area (brigade, division, corps, Service) quantities of personnel and equipment and the corresponding standard operating and investment costs.

Standard annual operating costs are the result of multiplying the quantities of personnel and equipment with the corresponding standard cost factors (e.g. annual cost of a major, maintenance cost per tank and km). These factors are average actual costs aligned with the price level of the current year.

Standard investment costs represent the value of the major and other equipment at replacement prices, for example of a tank battalion. These costs denote the amount of money to be spent for the procurement of equipment, if a battalion of this type is introduced into the army in the current year.

KOSMOS was developed by IABG, SZW for Armed Forces Staff Division Fü S VI 5, MoD Bonn, responsible for cost accounting in the Bundeswehr.

1.2 Estimating the Cost of Alternate Structures in the Case where the Units of the Structure are Already Specified

This is done by help of the KOSTPLA-model, which was developed by IABG, SZW for Army Staff Division Fü H VI.

The way KOSTPLA works: force structure costing can be compared with building a new house (=alternative force structure). A house is made of building stones (bricks). The bricks are the subunits, units, cost centers and cost areas stored in the KOSMOS DATA BANK.

The planner has to specify:

- types of subunits, units, cost centers and cost areas to be extracted from the KOSMOS DATA BANK
- modification rules (whether and in which manner the retrieved units are to be manipulated, e.g. replacement of a system for its successor, changes of quantities)
- number of the retrieved and possibly modified units to be entered into the alternative structure.

Once these planning specifications are entered into the System KOSTPLA calculates automatically costs and quantities of the alternative force structure.

1.3 Estimating the Cost of Future Structures in the Case where only the Weapon Systems of the Future Structure are known

The Input-/Output-model being utilized for this purpose was derived from economic Input-/Output-Analysis and has the name FUKO. It was developed for Army Staff Fü H VI. The terms Input and Output have the following meaning with respect to this model:

Output: Items and quantities of the weapon systems
Input: Quantities of personnel and equipment and its corresponding cost required by the weapon systems

The weapon systems are the end-products of the planning process or, put in words of economics, the final demand requiring certain amounts of supply (Input) to be satisfied. The basic assumption of the FUKO-model is that Input changes as the quantities of the weapon systems.

FUKO optionally applies two Input-/Output models, one being created by Leontieff and the other by Pichler. Leontieff-model: a certain branch (or cost center) provides one and only one product (or service) and there is no other branch able to do the same. Pichler-model: one branch can provide more than one product and there are other branches, producing some or all of these goods. Both models employ a system of linear equations, taking into account that a branch requires goods and services from other branches and vice versa. For example, generation of electricity demands coal and coal mining reciprocally requires electric power. An example related to the forces: maintenance units require medical services and vice versa. Both models calculate which goods are to be produced by which branches to meet the final demand, e.g. electric power for the households or maintenance hours for the weapon systems. The Pichler-model is mainly applied to chemical processes. For a comprehensive description of Input-/Output-models see the textbook of D. Zschocke with the title "Betriebsoekonometrie", edited 1974 in Würzburg, FRG.

FUKO has two Parts:

Part I : Allocating all the costs of the actual force structure to its weapon systems except for those costs that cannot readily be seen as being influenced by these systems (e.g. the cost of the Army band or those of the Minister of Defence)

Part II: Calculating the cost of an alternative future structure on basis of its weapon systems and the result of Part I.

1.3.1 Part I of the FUKO-Model

1.3.1.1 Direct Cost and Quantities of the Weapon Systems of the Actual Structure

These are the costs and quantities of the units that contain the weapon systems (e.g. tank units) and of the staff/service supply companies within the battalions (e.g. a tank battalion to which the tank companies pertain). Allocating the costs and quantities of these units to the weapon systems is simply done by aggregating the costs and quantities of the subunits belonging to these units (stored in the KOSMOS Data Base) by weapon systems and their missions and in addition to this by the functions of the subunits. That means firstly that for a weapon system occuring for example both in combat and in reconnaissance units, two different positions are made up in the calculation process and secondly that each quantity of personnel and equipment (e.g. trucks), is labeled by its function (e.g. combat, supply of ammunition). The results are stored in a data base. It is interesting to note that the items of personnel and equipment are characterized in this data base as to whether their relationship with the weapon system is a variable one (e.g. three soldiers in a tank) or a step-fixed one (one truck needed for supplying 1 through 12 tanks with ammunition).

In the case where a battalion consists of units which do not all have the same weapon system the subunits of the staff/service supply company are examined as to whether they are working for one or several weapon systems. In the latter case allocating to the weapon systems has to be done by appropiate keys.

In addition to storing the figures in a data base, the summarized results (subtotals and totals) are printed out (see direct costs in the example of fig. 1).

1.3.1.2 Indirect Cost of the Weapon Systems of the Actual Structure

Indirect costs are the costs of the support units at the brigade, division and corps levels, that means of the headquarters, maintenance, supply, communications and medical units. For each of these units the following data must be available: services rendered to each of the different weapon systems and to each of the other support units, the primary variable cost (before costs have been charged between the support units for services rendered to one another) and the step-fixed costs. Services are for example measured by maintenance man hours, persons to be treated, number of units subordinated.

Variable costs are those that fluctuate in proportion to changes in the volume of the services performed. These cost are allocated to the weapon systems by the help of a system of linear equations (based optionally on the Pichler or the Leontieff models), simultaneously taking into account that costs have to be reciprocally charged between the support units (see example, chapter 1.4.1).

Step-fixed costs are defined as being constant over a certain range of output but increasing by a discrete amount as activity moves from one range to the next. Example: costs for supervision personnel or for maintenance equipment. The step-fixed costs are simply allocated to the weapon systems on basis of the services rendered to them.

1.3.2 Part II of the FUKO-Model

1.3.2.1 Estimating the Direct Costs of the Future Structure

The operating costs of the future structure are calculated by applying a factor to the costs of each item of personnel and equipment of the actual structure, stored in the data base (see 1.3.1.1.):

IABG/SZW Fig. 1
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Input-Output-Model for the Army
Cost Mio DM

Weapon System: XXXXXXXXXXXX in Actual Structure

Quantity: xx

	Operating Cost/Year total	Operating Cost/Year per unit	15-years-LCC total	15-years-LCC per unit
Direct Operating				
Personnel	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Material	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Infrastructure	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Misc.	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Total Direct Operating	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Total Indirect Operating #)	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Total Operating	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Investment Cost (value of stocks on hand)				
Direct Investment	xx.xxx	xx.xxx	xx.xxx	xx.xxx
- Weapon System	(xx.xxx)	(xx.xxx)	(xx.xxx)	(xx.xxx)
Indirect Investment #)	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Total Investment	xx.xxx	xx.xxx	xx.xxx	xx.xxx
Total Operating + Investment (15 years)			xx.xxx	xx.xxx

#) with subdivisions by functions (e.g. maintenance, communic. etc.)

fn:dopl_s3a

$$CF_{ij} = CA_{ij} * FACT_i$$

CF_{ij} = Cost of item of equipment i (or personnel i), belonging to weapon system j, in the future structure

CA_{ij} = Cost of item of equipment i (or personnel i), belonging to weapon system j, in the actual structure

$FACT_i$ = Quantity of weapon system i in the future structure/Quantity of weapon system i in the actual structure

In the case of a step-fixed relationship the results are rounded up to the end of the range.

The procurement costs to be spent to arrive at the future structure are estimated in two steps:

- calculating the standard investment costs (value of stock on hand) of the future structure; this is done in the same way as shown above for the operating costs.

- summing up the differences between standard investment costs of the future structure and standard investment costs of the actual structure for those items of equipment, the quantities of which are increasing.

  The calculations described above relate to changes of quantities of existing weapons from actual to future structure. For new weapon systems the results of the correspondent LCC-analyses with respect to operating and procurement costs are introduced into the model. In the case where such figures for a new system are not available, the planner specifies an existing system to serve as basis for the cost calculations for the new system. Then the model provides a checklist with all the quantities and costs of the reference system, which can easily be modified by the planner as he sees fit.

1.3.2.2 Estimating the Indirect Costs of the Future Structure

Operating Costs

Variable Operating Costs are calculated for each weapon system and each suppo company as follows:

$$VF_{ij} = VA_{ij} * Fact_i$$

VF_{ij} = Variable Operating Costs for weapon system i in future structure in support company j

VA_{ij} = Variable Operating Costs for weapon system i in actual structure in support company j

$Fact_i$ = see above 1.3.2.1

Before calculating the step-fixed operating costs it is necessary to estimate for each support company the total amount of services to be rendered to weapon systems and other support companies. This is done by solving a system of linear equations (see 1.4.2). On the basis of the total services the step-fixed operating costs are calculated and allocated in the same way as illustrated for the actual structure in 1.4.1.

Procurement costs

The standard investment costs (stock on hand) have a step-fixed character. Therefore for each item of equipment what is examined is whether the total services to be rendered by a support company exceed the capacity of this item of equipment. If this is the case, an additional item of this kind is to be procured.

1.4 Mathematical Description of 1.3 by Examples

1.4.1 Allocating the Support Costs of the Actual Structure to the Weapon systems of the Actual Structure

Actual structure

Weapon System 1 (WS 1): 1000 units
Weapon System 2 (WS 2): 2000 units

These systems are supported by support companies U1 and U2, which also render services to one another.

Support company U1

- Service units (SU) to

* WS 1	20000 SU	= 1000 units * 20 SU/unit
* WS 2	5000 SU	= 2000 units * 2.5 SU/unit
* U2	4000 SU	
* U1 (own needs)	1000 SU	
Total	30000 SU	

- Primary cost (before reallocation)

* Variable cost for 30000 SU	100.000 DM
* Step-fixed cost for a range of 20000 SU	10.000 DM
* Step-fixed cost total for 30000 SU	20.000 DM (2 * 10.000)

Support company U2

- Service units to

* WS 1	1000 SU	= 1000 units * 1 SU/unit
* WS 2	3000 SU	= 2000 units * 1.5 SU/unit
* U1	2000 SU	
* U2 (own needs)	300 SU	
Total	6300 SU	

- Primary cost (before reallocation)

* Variable cost for 6300 SU	300.000 DM
* Step-fixed cost for a range of 10000 SU	30.000 DM
* Step-fixed cost for 6300 SU	30.000 DM

<u>Allocating the variable cost to the weapon systems (actual structure)</u>

This is done by solving the following system of linear equations:

(U1) 100000+1000*K1+2000*K2 = 30000*K1
(U2) 300000*4000*K1+ 300*K2 = 6300*K2

K1 = cost factor per SU of U1
K2 = cost factor per SU of U2

Solution:

K1 = 7.23 DM/SU
K2 = 54.81 DM/SU

U1 after reallocation

Primary variable cost	100000 DM	
from U2	+ 109630 DM	(2000 SU * 54.81 DM/SU)
to U2	- 28920 DM	(4000 SU * 7.23 DM/SU)
Total	180710 DM	
to WS 1	144580 DM	(20000 SU * 7.23 DM/SU)
to WS 2	36130 DM	(5000 SU * 7.23 DM/SU)
	180710 DM	

U2 after reallocation

Primary variable cost	300000 DM	
from U1	+ 28920 DM	(4000 SU * 7.23 DM/SU)
to U1	- 109630 DM	(2000 SU * 54.81 DM/SU)
	219290 DM	
to WS 1	54810 DM	(1000 SU * 54.81 DM/SU)
to WS 2	164480 DM	(3000 SU * 54.81 DM/SU)
	219290 DM	

Variable cost of the weapon systems

WS 1

	Total (f. 1000 units)	per unit
U1	144580 DM	144.58 DM
U2	54810 DM	54.81 DM
Total	199390 DM	199.39 DM

WS 2

	Total (f. 2000 units)	
U1	36130 DM	18.07 DM
U2	164480 DM	82.24 DM
Gesamt	200610 DM	100.31 DM

Total WS 1+2 = 400000 DM = Sum of primary variable cost of U1 and U2

<u>Allocating the step-fixed cost to the weapon systems (actual structure)</u>

(U1) Cost WS 1 = 20000 DM*20000 SU/25000 SU
= 16000 DM

Cost WS 2 = 20000 DM*5000 SU/25000 SU
= 4000 DM

(U2) Cost WS 1 = 30000 DM*1000 SU/4000 SU
= 7500 DM

Cost WS 2 = 30000 DM*3000 SU/4000 SU
= 22500 DM

1.4.2 Calculating the Total Amount of Service Units to be Rendered by each Support Company (Future Structure)

<u>Future structure</u>

Weapon System 1 (WS 1) = 3000 units
Weapon System 2 (WS 2) = 5000 units

Support company U1:

to WS 1	3000 units * 20 SU/unit	= 60000 SU
to WS 2	5000 units * 2.5 SU/unit	= 12500 SU
Total		72500 SU

Support company U2:

to WS 1	3000 units * 1 SU/unit	= 3000 SU
to WS 2	5000 units * 1.5 SU/unit	= 7500 SU
Total		10500 SU

The total service units TSU1 and TSU2 to be rendered by U1 and U2 are calculated by solving the following system of linear equations:

(U1) TSU1 = 72500 + 1000/30000*TSU1 + 4000/6300*TSU2
(U2) TSU2 = 10500 + 2000/30000*TSU1 + 300/6300*TSU2

The coefficients of this system (e.g. 4000/6300) are the so called coefficients of production. The coefficient 4000/6300 = 0.635 means that - for the production of one service unit TSU2 - support company U2 needs 0.635 service units TSU1 from support company U1. These coefficients are derived from the actual structure (see 1.4.1, e.g. 4000 = service units from U1 to U2; 6300 = Total Service units produced by U2).

Solution:

TSU1 = 86204
TSU2 = 17059

2. Planning of Weapon Systems, other Major Equipment and Ammunition to be procured/phased out to arrive at a planned Future Structure

2.1 Introduction

Once a year the German MoD draws up the "BUNDESWEHRPLAN", a document, in which you find for each Service (Army, Air Force, Navy, etc.) and for each of the 13 planning years (first planning year is the year after the next fiscal year):

* items and quantities of weapon systems, other major equipment (e.g. trucks) and ammunition, to be procured, together with the corresponding investment cost, calculated by applying the presumable procurement prices to these quantities
* average stock on hand for these materiel positions, together with the corresponding standard annual maintenance cost, calculated by applying standard annual cost factors to these stock positions
  average stock on hand = (stock at the end of the year + stock at the beginning of the year)/2
* quantities of infrastructure facilities, to be procured, together with the corresponding investment cost
* quantities of personnel by categories (e.g. officers) together with the corresponding standard annual personnel cost, calculated by applying standard annual cost factors to these quantities
* research and development costs
* other cost, such as POL- and miscellaneous operating cost.

When preparing the contributions of the Army to the BUNDESWEHRPLAN a major portion of the work to be done is related to the first two positions mentioned above, i.e. determining the quantities of weapon systems, other major equipment and ammunition to be procured or respectively to be phased out in each of the 13 planning years. This task has to be fulfilled for over a thousand items of material subject to the goal of meeting the enemy threat and to a lot of constraints, one major one being the fact that the sum of planned cost in a year must not exceed the financial means available for Army investments and Army maintenance in that year.

Millions of calculations are necessary before the plan for the Army can finally be approved by the decision makers. The reason for this is that planning is an iterative process, starting with the last plan for the Army within the BUNDESWEHRPLAN and then going on with continually presenting the provisional results (versions) of the new plan to the decision makers according to the progress of knowledge as to prices, financial means at disposal, etc. and above all with respect to the ranking (priorities) of weapon systems, specified by the decision makers.

To date, only the editing (documentation) of the planning results were supported by EDP, in 1986 IABG, department SZW was given the task by Army Planning Staff Fü H VI, MoD Bonn, to develop a mathematical model by means of which proposals for phasing-in and phasing-out of weapon systems, other major equipment and ammunition might be made on the basis of the input data to be delivered by the planners. The model, which has been designed and realized in close cooperation with the sponsor, was given the name DOPLA (Dynamic Optimization Model for Planning).

2.2 Results of the DOPLA-model

The model shows the way from the present stocks of weapon systems, other items of major equipment and ammunition to the stocks of the future Army structure plannend by the decision makers. This way describes for each item of this materiel, in which year which quantities are to be procured or respectively phased out in order to arrive at the future structure. Furthermore the model lists the amounts of money presumably to be spent for investment and maintenance, if the decision makers decide to follow the proposed way (see fig. 2). From the column "after 13" those quantities of the proposed future structure can be seen that cannot be realized until the time beyond the current time horizon. In addition to the listings DOPLA provides graphic pictures as to the differences between the current and the last version of the plan or between the current version and the approved plan of the year before (e.g. bars illustrating stretch-outs and postponements of systems).

The model essentially facilitates the work of the planner. To get an idea of the enormous calculation effort, one must have in mind that the introduction of only one new weapon system, until now not in the plan, or the cancellation or modification (postponement, stretch-out) of an item will affect a lot of other positions: because of the need to fit the budget ceiling other positions have to be cut back or respectively the amounts of money for other positions have to be increased accordingly.

Further it should be mentioned that modifications emerging at the last minute before the deadline can be quickly and easily transformed into the final version of the new plan for the Army.

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Fig. 2

Results of DOPLA

(Data Fictitious)

Item of Material	Actual Stocks at Beginning of year 0	Years — 0: Receipts (+) Outgoings (-) Inv.-Cost (*)	0: Average Stocks (o) Maint.-Cost (*)	1: Receipts (+) Outgoings (-) Inv.-Cost (*)	1: Average Stocks (o) Maint.-Cost (*)		13: Receipts (+) Outgoings (-) Inv.-Cost (*)	13: Average Stocks (o) Maint.-Cost (*)	after 13: Receipts (+) Outgoings (-) Inv.-Cost (*)	Intended Future Stocks
1 : :	10	+ 10 * 100	o 15 * 30	+ 30 * 300	o 35 * 70				— —	50
: :										
5 : :	0	——		——			+ 30 * 600	o 15 * 20	+ 70 * 1400	100
: :										
10 : :	50	- 20	o 40 * 60	- 30	o 15 * 23					0
N	100						- 100	o 50 * 60		0
Sub-Total Inv.-Cost Sub-Total Maint.-Cost Total Cost Budget Ceiling		XXXXXXX	 XXXXX XXXXX XXXXX	XXXXXXX	 XXXXX XXXXX XXXXX		XXXXXXX	 XXXXX XXXXX XXXXX	XXXXXXX XXXXXXX	

Receipts = Procurements

fn:donl sla - nec=courier15

When calculating the way from the present to the future structure the model takes into account the goals and restrictions specified by the planner. They are described in the next chapter in a written form. For a mathematical definition see Chapter 2.6.

2.3 Written Description of the Goal and the Restrictions of the DOPLA-Model

The goal of the model is defined as follows:

Determine the most efficient way to meet the enemy threat!

The most efficient way to do this is that one that maximizes the total effectiveness of the product mix over the planning period.

Total effectiveness of the product mix over the planning period	=	Result of summing up the effectivenesses of the product mixes of the 13 planning years
Product mix in a certain year	=	items and quantities of weapon systems, other equipment and ammunition, being available (stock on hand) in the Army units in that year
Effectiveness of the product mix in a certain planning year	=	Result of summing up the effectivenesses of the items of the product mix in that year
Effectiveness of an item of the product mix in a certain year	=	Quantity of the item (stock on hand) * * effectiveness per unit of the item

As the stocks can be expressed by receipts and outgoings, the aim of the model is defined as follows:

Determine receipts and outgoings for each of the 13 planning years so that the total effectiveness over the planning period will be maximized. This is to be performed subject to the following constraints:

- stock restriction: procurements must not be greater than the difference between intended future stocks and actual stocks; outgoings must not be greater than the difference between actual and future stocks. This implies that items with increasing stocks have no outgoings and items with diminishing stocks no receipts. In the case where replacements (new for old equipment) for an item with increasing stock are planned, there are two positions for this item in the plan, one for the procurements and another for the outgoings.
- budget restriction: the expenditure in a planning year for procuremments and maintenance must not exceed the budget ceiling for that year
- non-decreasing effectiveness: the effectiveness of the product mix in a year must be equal to or greater than that of the year before

- continuous procurement: once the procurement of an item is initiated, interruptions are no longer allowed, that means in each of the subsequent years procurements of this item have to go on unless the intended future stock of this item is reached.
  Option one: procurement of an item in a year is equal to or higher than that of the year before, but a maximum quantity must not be exceeded
  Option two: the procurement has to lie within a upper and a lower bound
- earliest possible procurement (delivery) year for each item
- prescribed ratio between an item to be procured and a certain item to be phased out
- prescribed ratio between an item to be procured and a certain other item to be procured.

2.4 How the DOPLA-model works

The problem at hand is a dynamic problem because it deals with time: procurement decisions for a certain year are influenced by decisions made for previous years and in turn govern the succeeding years. From a mathematical point of view it is interesting to note that DOPLA solves this problem by help of LP (linear programming). How the model works is briefly explained by the following example: there are 3 weapon systems (w1, w2 and w3) to be procured, the input data of which are as follows:

	w1	w2	w3
procurement price/unit (millions DM)	5	1	4
annual maint. cost/unit (millions DM)	0.2	0.02	0.3
effectiveness/ unit	5	0.5	8
effectiveness per 1 million DM spent in the year of procurement	0.98	0.5	1.93
earliest possible delivery year	0	1	2
maximum quantity of procurement/year	100	150	200
minimum quantity of procurement per year	80	100	100

Fig. 3 illustrates the results of solving this problem. In the rows "Str 1" you find the results of DOPLA. For better understanding of DOPLA the results of another simplified strategy not being fully dynamic are listed in rows "Str 2".

Results of "Str 2":
Beginning with year 1 "Str 2" maximizes the effectiveness year by year for each of the subsequent years separately. The main decision criterion is the effectiveness per 1 million DM spent for procurement and maintenance in the year of procurement. In the following this criterion is called EFFMONEY. The highest priority has the system with the highest EFFMONEY, for this system provides the most effectiveness for the unit of money to be spent. Though system w3 has the greatest EFFMONEY, it cannot be procured in year 1 because its earliest possible delivery year is year 2. As system w1 provides more EFFMONEY than w2, w1 is procured with the maximum possible quantity of 100 in year 1. For the rest of the money system w2 can be delivered with a quantity of 10. The procurement of w1 and w2 having been initiated in year 1, it has to go on in year 2, but only at the minimum quantity due to the greater EFFMONEY of system w3, which can be delivered with a quantity of 175, and so on.

Contrary to "Str 2" the DOPLA-model (see "Str 1") solves the problem by considering all planning years simultaneously. DOPLA starts with a basic solution and then pursues it by steadily improving the results subject to the total effectiveness over the planning period. Suppose, DOPLA would - on its way to the optimal solution - at random have arrived at the solution of "Str 2" as depicted in fig. 3. In order to check whether a further increase of effectiveness is possible DOPLA employs the so called simplex criterion of LP: for each variable (receipts/outgoings of an item in a year) what is examined is whether an increase of 1 piece leads to a higher effectiveness over the planning period. Because of the budget restriction this check has to take into account that the additional numbers induce lower quantities for other items. In our case DOPLA found out that one more piece of w3 in year 2 has an impact of 10.2 additional units of effectiveness over the planning period. Therefore procurement of w3 is increased by 25 in year 2, so that the maximum possible quantity of 200 is achieved. As a consequence the first delivery of w2 has to be postponed to year 3 with further consequences in years 3 and 4 (see fig. 3).

Compared with the simplified strategy "Str 2" the DOPLA-LP-strategy "Str 1" has the following essential advantages:

- DOPLA considers the maintenance cost over the whole planning period, thus making sure that the whole cost of the systems are taken into account: higher procurement cost may be more than balanced by lower maintenance cost
- DOPLA makes allowances for the fact that the introduction of a new system requires financial means not only in the first year but - because of maintenance cost and the need to produce continually - also in the subsequent years, money which is no longer available for other systems, being ready for first delivery in these later years and possibly being able to provide higher contributions to overall effectiveness than the system initially phased-in in the previous year. So it was favourable to postpone initial procurement of system w2 from year 1 to year 3, thus

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Fig. 3

Example of how DOPLA works
(Data Fictitious)

Item of material		Act. stocks at end of year 0	Years/Receipts (Procurements)				Intended Future Stocks
			1	2	3	4	
W 1	Str 1	100	100	80	80	40	400
	Str 2		100	80	91	29	
W 2	Str 1	0	-	-	150	150	300
	Str 2		10	100	100	90	
W 3	Str 1	0	-	200	200	-	400
	Str 2		-	175	200	25	
Budget Ceiling		-	541	1278	1506	551	Total 3876,0
Cost (Invest + Maint)	Str 1		530	1278	1505,5	550,5	3864,[illegible]
	Str 2		540,1	1275,6	1505,7	533,5	3854,9
Effectiveness	Str 1		1000	3000	5075	5350	14425
	Str 2		1005	2855	4960	5350	14170

fn:dopl_s2

making possible higher quantities for system w3 in year 2 (see fig. 3). So in some instances it may be advisable not to spend all the money available in a year (see year 1 in fig. 3).

2.5 Determining Quasi-Effectiveness Figures for Items, for which those Values are not available from Wargaming

This is done in the following way:

- defining priority classes (by planner)
- allocating the systems which lack effectiveness values from wargaming to one of these classes (by planner)
- allocating each of the priority classes to a range, within which the ratios "quasi-effectiveness per 1 million DM" of the systems belonging to this class shall lie. Doing this the planner takes into account the 'effectiveness per 1 million DM' of those systems, for which effectiveness figures from wargaming are available.
- calculating this ratio for each of the systems subject to the regulation: the higher the total 10 years cost of a system compared with the other systems of the same class the lower the ratio (by model)
- calculating the "quasi-effectiveness per unit" for each of the systems by multiplying the "quasi-effectiveness per 1 million DM" with the 10 years cost per unit (by model).

Definitions:

a) effectiveness per 1 million DM = $\frac{\text{effectiveness per unit (from wargaming)}}{\text{10 years cost per unit}}$

b) 10 years cost per unit = procurement price + 10 years maint.-cost per unit

c) total 10 years cost = quantity of the system to be procured in the planning period * b)

2.6 Mathematical Description of the DOPLA-Model

Two groups of material are to be distinguished:

- items i = 1, 2, ...nz, whose intended future stocks are higher than the actual stocks. It is assumed for these items that there are only quantities incoming (receipts) and not any quantities outgoing during the planning period

- items i = nz+1, nz+2, ...n, the future stocks of which are lower than the actual stocks. It is assumed that there aren't any receipts during the planning period

2.6.1 Objective Function

Maximize the effectiveness over the planning period =

$$\text{Max} \sum_{j=1}^{t} \sum_{i=1}^{n} b_{ij} \cdot c_i$$

b_{ij} = stock of item i in year j
c_i = effectiveness of item i per unit of this item

This function can be transformed into:

$$\text{Max} \sum_{j=1}^{t} \sum_{i=1}^{nz} (t-j+1) * c_i * e_{ij} -$$

$$- \sum_{j=1}^{t} \sum_{i=nz+1}^{n} (t-j+1) * c_i * a_{ij}$$

e_{ij} = receipts of item i in year j
a_{ij} = outgoings of item i in year j

2.6.2 Constraints for the Objective Function

2.6.2.1 Actual Stocks and Intended Future Stocks

For items with increasing stocks:

$$\sum_{j=1}^{t} e_{ij} = E_i - A_i \quad \text{for } i=1, 2, \ldots, nz$$

and for items with decreasing stocks:

$$\sum_{j=1}^{t} a_{ij} = A_i - E_i \quad \text{for } i=nz+1, nz+2, \ldots, n$$

A_i = Stock of item i in the actual structure
E_i = Stock of item i in the intended future structure

2.6.2.2 Budget Ceiling per Year

$$\sum_{i=1}^{n} b_{ij} * betr_i + \sum_{i=1}^{nz} inv_i * e_{ij} \leq H_j$$
$$\text{for } j = 1,2, \ldots, t$$

b_{ij} = average stock of item i in year j
$betr_i$ = maintenance cost per year and unit of item i
inv_i = procurement cost per unit of item i
H_j = budget ceiling for investment and maintenance in year j

The latter form can be translated into:

$$\sum_{i=1}^{nz} \sum_{l=1}^{j} betr_i * e_{il} - \sum_{i=1}^{nz} betr_i * 0,5 * e_{ij} -$$

$$- \sum_{i=nz+1}^{n} \sum_{l=1}^{j} betr_i * a_{il} + \sum_{i=nz+1}^{n} betr_i * 0,5 * a_{ij} +$$

$$+ \sum_{i=1}^{nz} inv_i * e_{ij} \leq H_j - BA; \text{ for } j = 1, 2, \ldots, t$$

BA are the maintenance cost of the considered items in the actual structure (year 0).

$$BA = \sum_{i=1}^{n} betr_i * b_{io}$$

2.6.2.3 <u>Non-Decreasing Effectiveness over the Planning Period</u>

$$\sum_{i=1}^{nz} c_i * e_{ij} \geq \sum_{i=nz+1}^{n} c_i * a_{ij}$$

for j=1, 2, ..., t

2.6.2.4 <u>Continuous Procurement</u>

<u>Option 1:</u> Non-Decreasing Receipts from Year to Year with Upper Limits

<u>Non-Decreasing Receipts</u>

$$e_{ij} - e_{ij-1} + (Ei - A_i) * S_{ij} \geq 0$$

where

$$S_{ij} = \begin{cases} 0 \text{ for } \sum_{l=1}^{j-1} e_{il} < (E_i - A_i) \\ 1 \text{ for } \sum_{l=1}^{j-1} e_{il} = E_i - A_i \end{cases}$$

for j=2, 3, ..., t and i= 1, 2, ..., nz

The last condition is fulfilled by the following inequality:

$$2 * S_{ij} - \frac{1}{E_i - A_i} * \sum_{l=1}^{j-1} e_{il} \leq 1$$

for j=2, 3, ..., t and i= 1,2, ..., nz

$$S_{ij} = \{0,1\}$$

Upper Limits lo_{ij}

$$e_{ij} \leq lo_{ij}$$

for $j = 1, 2, \ldots, t$ and $i = 1,2, \ldots, nz$

Option 2: Continuous Receipts from Year to Year within Upper and Lower Limits

Upper Limits

$$e_{ij} \leq lo_{ij}$$

Lower Limits

$$e_{ij} - S_{ij} * lu_{ij} \geq 0$$

where

$$S_{ij} = \begin{cases} 1 \text{ for } b_{ij-1} < E_i \\ 0 \text{ for } b_{ij-1} = E_i \end{cases}$$

for $j = 1, 2, \ldots, t$ and $i = 1, 2, \ldots, nz$

The latter condition can be transformed into the following inequality:

$$S_{ij} + \frac{1}{E_i - A_i} * \sum_{l=1}^{j-1} e_{il} \geq 1$$

for $j = 1, 2, \ldots, t$ und $i = 1,2, \ldots, nz$

$$S_{ij} = \{0,1\}$$

lo_{ij} - Upper Limits for receipts of item i in year j
lu_{ij} - Lower Limits for receipts of item i in year j

2.6.2.5 Earliest Possible Delivery Year tm for System k

$$e_{kj} = 0 \text{ for } j = 1, 2, \ldots t_{m-1}$$

2.6.2.6 Replacement Rules

$$e_{ij} \ (\overset{=}{\geq}) \ \text{Fakt} * a_{kj} \quad \text{for } j = 1, 2, \ldots, t$$

for a certain incoming item i and for a certain item k to be phased out, FAKT specifies the ratio between receipts and outgoings.

2.6.2.7 Link between Receipts of item i and Receipts of item k

$$e_{ij} = \text{Mult} * e_{kj} \quad \text{for } j = 1, 2, \ldots, t$$

Mult is the link factor.

SUMMARY REPORT PREPARED FOR THE ARMY OPERATIONS RESEARCH SYMPOSIUM

A STUDY OF THE FEASIBILITY OF ELIMINATING THE 2 1/2 TON PAYLOAD TRUCK CLASS

BY

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1. PURPOSE

The US Army has initiated the Family of Medium Tactical Vehicles (FMTV) program to acquire Light Medium Tactical Vehicles (LMTV) (2 1/2-ton) and Medium Tactical Vehicles (MTV) (5-ton) and associated trailers. This study examines the feasibility of alternative mixes of 5/4-ton and 5-ton trucks with associated trailers that would provide (without the LMTV variant):

- o increased capability (with respect to the proposed FMTV program) at comparable cost, and,
- o capability comparable to that provided by the proposed FMTV program at less cost.

In addition, the potential manpower and operating cost implications of removing the LMTV variant from the FMTV fleet are analyzed.

2. METHODOLOGY

Figure 1 presents an overview of the methodology applied to the analysis.

The first two steps in the methodology were based upon the 65,098 2 1/2-ton truck requirement of the FY97 Objective Force as defined in the Force Accounting System (FAS) and modified by the application of the FMTV BOIP. Unit and vehicle missions were defined by current Table of Organization and Equipment (TOE) documentation. Detailed analysis of vehicle requirements within all TOEs was beyond the scope of this study. A subset of 134 SRCs, including 35,995 2 1/2-ton trucks in 260 distinct TOEs, was selected by the study team and approved by the Study Advisory Group (SAG) for detailed analysis. These TOEs included representative samples of all Active Army, National Guard, Army Reserve, and POMCUS organizational structures and all combat, combat support, and combat service support organizations. All TOEs of the four types of active Divisions were analyzed.

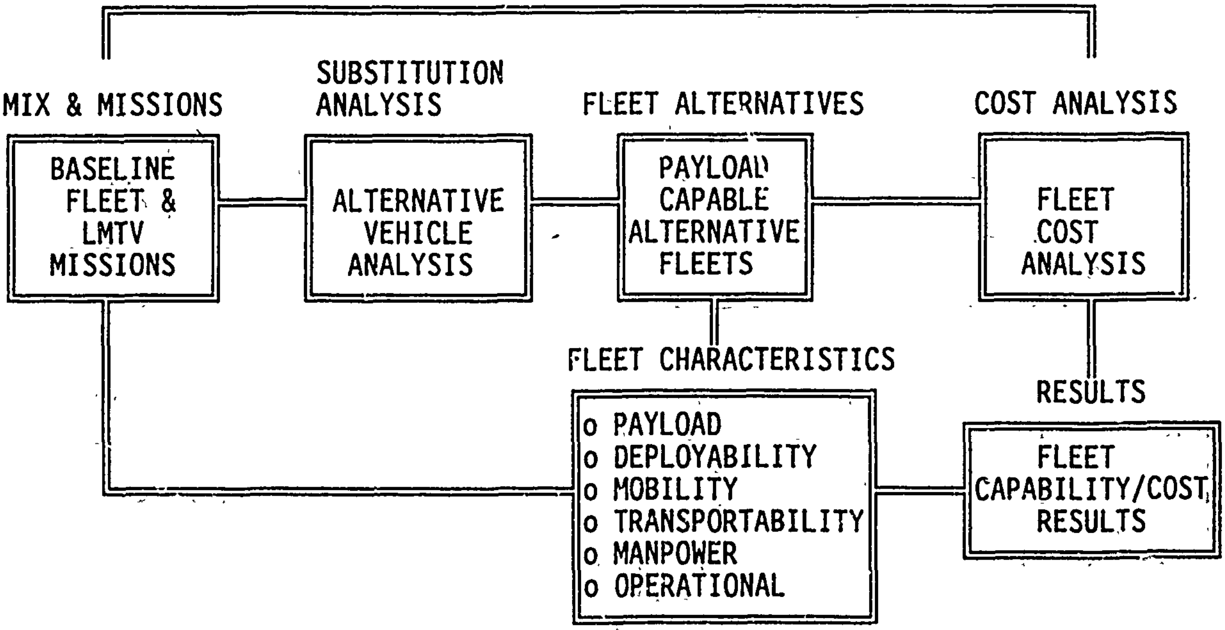

FIGURE 1. METHODOLOGY OVERVIEW

Per SAG guidance, the Army's Tactical Wheeled Vehicle Modernization Plan Procurement Strategy objective of 30,467 LMTVs and 67,413 MTVs was defined as the Baseline Force. The results of the analysis of the 134 SRCs was extrapolated to this force to develop six alternative vehicle fleets for comparison with the Baseline Fleet. The first alternative was developed by the Tactical Wheeled Vehicle Requirements Management Office (TWVRMO) at Fort Eustis. In this alternative (later referenced as the TWVRMO-HVY alternative), all 2 1/2 ton trucks were replaced by 5-ton trucks in keeping with Army policy requiring minimum items of equipment. SAIC developed substitution algorithms leading to three additional alternatives. Alternative 2 (LIGHT) substituted 5/4-ton trucks for 2 1/2 ton trucks wherever possible; Alternatives 3 (HEAVY-CONSO) and 4 (LIGHT-CONSO) consolidated loads within and between sections, minimizing the number of 5-ton trucks required in Alternatives 1 and 2, respectively. Two additional alternatives were developed as sensitivities. Alternative 5 assumed the existence of a 5/4-.. trailer in place of the 3/4-ton trailer in Alternative 4. Alternative 6 modified Alternative 4 by assuming no CUCVs in the force.

Following the development of the force alternatives, fleet costs were developed and fleet characteristics were analyzed.

3. OPERATIONAL ANALYSIS

Truck Analysis. Table 1 presents the baseline truck fleet and each of the alternatives.

TABLE 1. TOTAL TRUCKS BY ALTERNATIVE

TYPE	BASE	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
LMTV	30467	0	0	0	0	0	0
MTV	67413	97880	96517	97830	96467	96467	96467
HMMWV	0	0	1524	0	1524	1327	2410
CUCV	0	0	886	0	886	771	0
TOTAL TRUCKS	97880	97880	98927	97830	98877	98565	98877
% CHANGE	N/A	0.0	+1.1	-0.1	+1.0	+0.7	+1.0

In Alternative 1, it can be seen that all LMTVs are replaced by MTVs, resulting in the same total number of vehicles. In Alternative 2, LMTVs are replaced by MTVs, and, wherever possible, by HMMWVs or CUCVs. It can be seen that there were limited opportunities for the substitution of 5/4-ton trucks for LMTVs. In all, 95% of the LMTVs were replaced by MTVs. This was because of the LMTVs mission as prime moves for various non-cargo trailers and trailer mounted systems (40%), the configuration of LMTV loads being incompatible with downsizing (50%), and secondary missions of the LMTV (5%). In Alternatives 3 and 4, a reduction of only 50 MTVs can be seen resulting from the consolidation of loads within or between sections. When the 5/4-ton trailer was assumed in Alternative 5, a savings of 312 5/4-ton trucks resulted. In Alternative 6, the 771 CUCVs in Alternative 4 were converted to HMMWVs, resulting in the same number of 2410 5/4-ton trucks. Thus, in each alternative, the total number of trucks in the fleet varies by 1.1% or less from the Baseline.

Trailer Analysis. Table 2 presents the results of the trailer analysis.

TABLE 2. TOTAL TRAILERS BY ALTERNATIVE

TYPE	BASE	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
3/4-TON	0	0	1786	0	1786	1685	1786
5/4-TON	0	0	0	0	0	413	0
1 1/2-TON	31518	31518	30676	31518	30676	30676	30676
2 1/2-TON LMTV	10910	10910	10859	10910	10859	10859	10859
5-TON MTV	827	827	827	827	827	827	827
TOTAL TRAILERS	43255	43255	44148	43255	44148	44460	44148
% CHANGE	N/A	0.0	+2.1	0.0	+2.1	+2.8	+2.1

It can be seen that there is little variation in the number of trailers between the alternatives and the Baseline. Of special interest is the fact that a requirement was identified for only 413 5/4-ton trailers in Alternative 5. The 413 5/4-ton trailers reduced requirements for 3/4-ton trailers by 101 to and 5/4-ton trucks by 312.

4. COST ANALYSIS

The objective of the cost analysis is to determine the cost implications of eliminating the proposed LMTV tactical truck from the proposed FMTV program. This analysis includes a Life Cycle Cost (LCC) assessment and an assessment of cost sensitivities including a separate evaluation of the logistics impact of the elimination of the LMTV from the FMTV program. LCC analysis techniques were applied to the base line and alternative fleets developed as a result of the substitution methodology. Alternative fleets were designed to meet the Army's truck requirements as stated in the US Army Truck Modernization Plan procurement objective. These alternative fleets were compared to the Baseline fleet which contains both the planned FMTV (LMTV and MTV) trucks.

Ground rules and assumptions were established to insure consistent treatment of alternatives and comparability of results. These ground rules identified the current TWV Modernization Plan as the basis for costs including vehicle life, annual miles, and personnel assignments. Costs were developed in accordance with Army cost analysis instruction, DCA-P-92(R), Instructions for Reformatting the BCE/ICE. The foundation of the cost analysis rests upon several key assumptions. The following is a listing of those ground rules and assumptions.

Development costs are considered sunk for the FMTV program.

The Unit Procurement Cost (UPC) is a cost used to capture all production related costs under cost element 2.0, as defined by DCA-P-92. UPC's were collected from TACOM (AMSTA-VCW) for each truck in a family, such as the ten trucks comprising the five ton MTV vehicle class. An analysis was performed to develop weighted UPC's based on TACOM's data and the quantities associated with each fleet. The weighted unit cost reflects the actual mix of vehicle variants in each fleet. In addition, costs for applicable kits and federal excise tax on specific vehicles were included in the development of the weighted UPC.

To provide a common basis for cost comparison, all cost data has been normalized to FY90 constant year dollars.

UPCs are multiplied by the quantity per year to generate production costs. No learning curve (cost quantity price break) is considered.

Quantities in the Baseline vehicle fleet are shown as either active, reserve or POMCUS vehicles.

Production costs include vehicle rebuys. That is, vehicles produced in previous years which have operated for their full life are replaced at the end of their life.

Planned production of vehicles begins in FY91. This is to maintain consistency with the truck modernization plan.

A residual value calculated as the ratio of the life divided by the years operated is applied to the cumulative production cost. This figure reflects, in dollars, the value of remaining life available for each vehicle by FY2020.

Values for vehicle life are based upon data received from Tank and Automotive Command (TACOM) Fleet Planning Office. These values are the following:

MTV	22 years
LMTV	20 years
HMMWV	14 years
CUCV	7 years
All Trailers	30 years

The worldwide average fielding cost for each vehicle was provided by TACOM and used as a one time per unit cost in the year fielding occurs. Fielding occurs one year after production.

No Military Construction Appropriation (MCA) was estimated in this analysis.

Operating costs will begin in FY91, which corresponds to the Initial Operational Capability (IOC) in the FMTV program. The operating phase of this analysis will end in the last procurement fiscal year, 2020.

Direct operating costs (excluding crew) on a per vehicle basis are calculated based upon three factors provided by the Fleet Planning Office at TACOM. These factors represent sustainment cost data collected under the Sample Data Collection (SDC) program by PICO Co. for the Army. SDC data used in this study is exactly that data used by TACOM's Fleet Planning Office and the United States Army Cost and Economic Analysis Center (USACEAC) to develop sustainment cost estimating equations for the truck modernization plan.

- Fixed annual costs are those costs which will not vary with vehicle age or annual mileage. These costs include scheduled maintenance, war reserve OMA/ASF repair parts, war reserve procurement spares, maintenance related transportation costs, modification kits, and "Other Sustainment".

- Variable costs include costs for POL (petroleum, oil, and lubricants) and are a function of annual miles driven.

- The annual cost of unscheduled maintenance (man hours and parts) data has been collected to be modelled as a linear function of both vehicle age and annual miles driven per year.

Active vehicles are estimated at 100% of the annual unit sustainment cost. The percentage used for Reserve vehicles is determined based upon actual historical mileage per vehicle collected through Sample Data Collection (SDC). The percentage used for all Reserve vehicles is 70% of the Active sustainment cost. POMCUS vehicles are costed at 10% of the Active sustainment cost.

The number of maintenance personnel associated with each fleet, are derived from factors for the number of maintenance men per truck per year times the quantity of active, reserve and POMCUS vehicles.

Miles per year reflects each vehicle's actual mileage as provided by TACOM's Fleet Planning Office and captured by SDC efforts. The annual miles driven are determined by the vehicle role not by the vehicle type, i.e., all vehicles performing the LMTV mission utilize the LMTV annual mileage.

Costs for the DCA-P-92 sustainment cost element 5.081 (Crew Pay and Allowance) are developed on a per vehicle basis using a crew cost times the number of assigned drivers.

Costs associated with DCA-P-92 cost element 5.082 (Maintenance Pay and Allowance) are captured in the formula for direct operating cost.

The value used for the number of assigned drivers for each vehicle is based on the particular mission/role of a vehicle and not vehicle type. In other words, MTV vehicles acting as replacement vehicles for the LMTV reflects the LMTV number of assigned drivers. Listed below are the values used in this analysis.

BASELINE FLEET		ALTERNATIVE FLEET	
MTV	.25	MTV (5-ton role)	.25
LMTV	.10	MTV (2 1/2-ton role)	.10
HMMWV	.00	HMMWV (2 1/2-ton role)	.10
CUCV	.00	CUCV (2 1/2-ton role)	.10

The Army Cost Analysis guidance DCA-P-92(R), Instructions for Reformatting the BCE/ICE, was used to develop the cost element structure. Data were collected to complete the cost analysis and develop cost estimating relationships (CER). Production and fielding cost data were obtained through TACOM's (AMSTA-VCU) cost analysis division. Sustainment cost data were obtained from TACOM's Fleet Planning Office. All data were reviewed with the study cost analysis proponents. These proponents included US Army Cost and Economic Analysis Center (USACEAC), TACOM's Cost Analysis Division, Tactical Wheeled Vehicle Procurement Executive Office (PEO), and the SAG. All sustainment cost data agrees with that used for the tactical wheeled vehicle modernization plan. The generic vehicle cost used for production estimates represents the weighted average cost for the vehicle mix in the alternative fleets. The cost data are presented in Table 3.

An automated cost analysis model was developed to prepare cost estimates for each alternative. The model allowed the calculation of costs by vehicle and fiscal year. In addition the model uses an equation to calculate the direct operation cost of vehicles such that they are more expensive as they age. The key cost drivers in the model are unit cost (represented by the weighted average Unit Procurement Cost), vehicle life, and annual miles driven. The model also allowed the assessment of alternatives constrained by funding and/or time.

TABLE 3. TRUCK STUDY COST DATA
(FY90 CONSTANT $ THOUSANDS)

VEHICLE TYPE	LIFE	MILES	UPC	UNIT FIELDING	MID-LIFE SUSTAINMENT
LMTV (GENERIC)	20	2512	$ 61.4	$7.5	$4.5
CARGO			$ 59.4		
VAN			$ 84.9		
MTV (GENERIC)	22	3054	$ 86.3	$10.4	$7.9
MTV(LMTV)	22	2512	$ 86.3	$10.4	$5.6
MTV (Alternatives)			$ 83.7		
CARGO			$ 72.9		
CARGO LWB			$ 75.9		
CARGO W/MHE			$ 98.1		
CARGO LWB W/MHE			$100.2		
VAN			$132.4		
DUMP			$ 79.2		
WRECKER			$182.2		
POL (1500 GAL)			$104.4		
TRACTOR			$ 72.3		
AMBULANCE			$205.2		
HMMWV	14	2512	$ 24.6	$2.7	$1.6
CUCV	7	2512	$ 17.5	$2.3	$1.2
TRAILERS					
3/4-TON	30	-	$ 2.5	$0.5	$2.6
1 1/2-TON	30	-	$ 4.7	$0.9	$1.3
2 1/2-TON	30	-	$ 15.0	$1.7	$1.3
5-TON	30	-	$ 18.0	$2.4	$2.5
NEW 5/4	30	-	$ 6.1	$0.9	$1.2

Table 4 presents the sustainment cost data used in the analysis.

The final step in the process included the testing of the model before cost estimates were developed. This testing included an assessment of the logic and numeric output. Once analytic credibility of the model was established, initial cost estimates were developed. As an additional check, emerging results were presented to the TACOM PEO and Cost Analysis Division for review.

The results of the cost analysis are displayed in Table 5. The results include the cost of rebuys to maintain the fleet as vehicles reach their life expectancy

TABLE 4. TRUCK STUDY SUSTAINMENT DATA
(CONSTANT FY90 $ THOUSANDS)

	TRANS	SCHD MAINT	MOD KIT	OTHER COSTS	TOTAL CONSTANT
HMMWV	0.0249	0.1243	0.1212	0.0000	0.27
CUCV	0.0249	0.2020	0.0684	0.0000	0.29
LMTV	0.0725	0.2310	0.2258	0.0352	0.56
MTV	0.1274	0.2258	0.3098	0.0445	0.70
MTV(LMTV)	0.1274	0.2258	0.3098	0.0445	0.70
TRAILER	0.00	0.00	0.00	0.0000	2.40
TRAILER	0.00	0.00	0.00	0.0000	1.02
LMTV TRLR	0.00	0.00	0.00	0.0000	1.06
MTV TRLR	0.00	0.00	0.00	0.0000	1.90
TRAILER	0.00	0.00	0.00	0.0000	0.93

	SLOPE FACTORS UNSCHED MAINT($)	DEPOT MAINT AVG $/YR	DEPOT MAINT. SLOPE($/MI/YR)	INTERCEPT VALUES UNSCHD MAINT ($/MI)
HMMWV	0.000024	0.2103	0.000007	0.000128
CUCV	0.000016	0.1948	0.000009	0.000117
LMTV	0.000079	0.4735	0.000019	0.000322
MTV	0.000097	0.6713	0.000020	0.000341
MTV(LMTV)	0.000097	0.6713	0.000020	0.000341

	POL ($/MI)	TTL ACTIVE ANUAL MILES	TTL RESERVE % OF MILES	TTL SUST % FOR POMCUS	TTL SLOPE ($/MI/YR)
HMMWV	0.0001	2512	0.70	0.10	0.000032
CUCV	0.0001	2512	0.70	0.10	0.000025
LMTV	0.0001	2512	0.70	0.10	0.000098
MTV	0.0002	3054	0.70	0.10	0.000117
MTV(LMTV)	0.0002	2512	0.70	0.10	0.000117
TRAILER		4149	0.70	0.10	0.000006
TRAILER		2512	0.70	0.10	0.000008
LMTV TRLR		2512	0.70	0.10	0.000007
MTV TRLR		3054	0.70	0.10	0.000014
TRAILER		4149	0.70	0.10	0.000009

	TTL INTERCEPT ($/MI)	CRT AGE	CURRENT COST ($K/YR)	CURRENT COST ($K/MI)
HMMWV	0.000213	1.37	0.99	0.0004
CUCV	0.000180	3.90	0.99	0.0004
LMTV	0.000470	0.00	1.75	0.0007
MTV	0.000550	0.00	2.39	0.0008
MTV(LMTV)	0.000550	0.00	2.09	0.0008
TRAILER	0.000000			
TRAILER	0.000000			
LMTV TRLR	0.000000			
MTV TRLR	0.000000			
TRAILER	0.000000			

TABLE 5. COMPARISON FOR BASE CASE AND ALTERNATIVES (97,880)
(FY90 CONSTANT $ BILLIONS)

CATEGORY	B L	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
PRODUCTION	$10.18	$10.82	$10.77	$10.81	$10.76	$10.75	$10.76
FIELDING	1.20	1.31	1.30	1.31	1.30	1.30	1.30
SUS	8.24	8.63	8.63	8.63	8.63	8.63	8.63
TOTAL	19.62	20.76	20.70	20.75	20.69	20.68	20.69
CHANGE	--	5.8%	5.5%	5.8%	5.5%	5.4%	5.5%
RESIDUAL VALUE	$ 5.01	$ 5.45	$ 5.40	$ 5.45	$ 5.40	$ 5.40	$ 5.40
TOTAL LESS RESIDUAL	14.61	15.31	15.30	15.30	15.29	15.28	15.29
CHANGE	—	4.8%	4.7%	4.7%	4.7%	4.6%	4.7%
FIXED COST FOR MTV	$14.39	$14.39	$14.39	$14.39	$14.39	$14.39	$14.39
TOTAL W/O FIXED	5.23	6.37	6.31	6.36	6.30	6.29	6.30
CHANGE	--	21.8%	20.7%	21.6%	20.5%	20.3%	20.5%

It was found that each of the alternatives was approximately 5.4% to 5.8% more costly than the baseline. However, in cost estimating, differences of less than ten percent are not considered significant. Examination of the residual value of fleets, likewise, offered little insight since all fleets are procured at about the same rate and the residual value is very similar in each case. $14.39 billion of the total LCC for the Baseline and any Alternative are attributable to the 67,413 MTVs which are common to each. When the cost impact of this large fixed cost is removed, the alternative fleets vary from 20.3% to 21.8% more expensive than the Baseline. This change, which reflects expected cost increases experienced if the LMTVs were eliminated, is significant and adds meaning to the estimated 5+% increase in fleet costs when the costs of the 67,413 MTVs common to all alternatives are considered. Table 6 provides a look at the impact of sustainment costs. This table shows that the annual sustainment cost increase for each of the alternative fleets is about $30M or 4.2% to 4.9% greater than the $669M Baseline costs when the fleets are fully fielded.

Sensitivities were analyzed including a constrained funding case, increased life expectancy of the HMMWV and CUCV, an increase in annual miles driven for the 5/4-ton truck in the LMTV role, and, increases in the number of drivers for the MTV and decreases for the 5/4-ton truck when performing in the LMTV role. In no case was the sensitivity found to be significant.

TABLE 6. SUSTAINMENT COST IMPACTS ON FULLY FIELDED REQUIREMENT
(FY90 CONSTANT $ MILLIONS)

	B L	ALT 1	ALT 2	ALT 3	ALT 4	ALT 5	ALT 6
VEHICLE QUANTITIES							
HMMWV	0	0	1,524	0	1,524	1,327	2,410
CUCV	0	0	886	0	886	771	0
LMTV	30,467	0	0	0	0	0	0
MTV	67,413	67,413	67,413	67,413	67,413	67,413	67,413
MTV(LMTV)	0	30,467	29,104	30,417	29,054	29,054	29,054
TOTAL	97,880	97,880	98,927	97,830	98,877	98,565	98,877
TOTAL ANNUAL SUSTAINMENT COSTS (ALL VEHICLES OPERATIONAL)							
COST	$669	$702	$698	$702	$698	$697	$698
%INCREASE		4.9%	4.3%	4.9%	4.3%	4.2%	4.3%

A logistics assessment was conducted to include special tools, training, publications, National Stock Numbers, retail parts, wholesale parts and facilities. It was found that there is a net logistics cost of approximately $187M to $200M resulting from the elimination of the LMTV fleet. This increase stems primarily from the costs associated with the retail and wholesale parts inventory. These costs were included in the LCC results presented earlier. Table 7 summarizes the findings of this analysis.

TABLE 7. LOGISTICS ASSESSMENT SUMMARY
(FY90 CONSTANT DOLLARS IN MILLIONS)

ELEMENT	COST		SAVINGS	
	ANNUAL	ONE TIME	ANNUAL	ONE TIME
1. SP. TOOLS	$0	$0	$0	$0
2. TRAINING	$0	$0	$0	$0
3. PUBS	*	$0	*	$1
4. NSN				
ESTABLISH	$0	$0	$0	$0 to $3
MAINTAIN	$0	$0	**	$0
5. RETAIL INVENTORY	$0	$48 to $50	$0	$19
6. WHOLESALE INVENTORY	$0	$207 to $218	$0	$49
7. FACILITIES	$0	$0	$0	$0
TOTAL IMPACT	$0	$255 to $268	$0	$68

* Directly accounted for in the LCC
** Less than $1 million over ten years

The total logistics savings from the elimination of the LMTV fleet are estimated to be $68 million. These savings are off-set by a cost increase from $255 million to $268 million due to an increase in retail and wholesale inventory due to the increased number of MTV in the fleet. Therefore, the elimination of the LMTV from the FMTV family causes a probable cost increase of $187 million to $200 million. When this value is compared to the $20 billion associated with the FMTV fleet, the summary conclusion is that no significant logistics impacts are discovered as a result of the elimination of the LMTV from the FMTV family.

The lack of significant findings is explained by two factors. The LMTV is one member of a family of vehicles designed to incorporate the benefits of commonality. Thus, fewer elements of the program are eliminated than might have been expected. Also, the LMTV is replaced in most cases with a more expensive MTV. Thus logistics costs increase in most cases.

5. FLEET CHARACTERISTICS

An analysis of the Baseline and Alternative fleet characteristics, including payload capacity, strategic deployability, mobility, transportability, and manpower requirements was conducted. Results are presented subjectively in Table 8.

TABLE 8. ADVANTAGES AND DISADVANTAGES OF FLEET ALTERNATIVES

ALTERNATIVE	WEIGHT	CUBE	SORTIES	MOBILITY	TRANSPORT-ABILITY	MAN-POWER
BASELINE	o	o	o	o	o	o
1. TWVRMO (HVY)	+	+	-	+	o	-
2. LIGHT	+	+	-	+	+	-
3. HEAVY-CONSO	+	+	-	+	o	-
4. LIGHT-CONSO	+	+	-	+	+	-

\+ Advantage   - Disadvantage   o No Change

Weight and cube capability of each of the alternatives is significantly greater than the Baseline Fleet. It should be pointed out that the Baseline Fleet is currently capable of performing its load hauling mission. An assessment of the desirability of the added capability was beyond the scope of this study.

All alternatives require more sorties for strategic deployability than the Baseline Fleet.

Alternatives 1 and 3, where only the MTV substitutes for the LMTV, have enhanced mobility compared with the Baseline Fleet. Since 5/4-ton trucks have reduced mobility compared to the LMTV, the mobility of Alternatives 2 and 4, which contain less than 3% 5/4-ton trucks, was slightly less than Alternatives 1 and 3 but still improved when compared with the Baseline Fleet. An assessment of the enhanced mobility of Alternatives 1 and 3 was beyond the scope of the study.

In that 5/4-ton trucks can be lifted by UH-60 helicopters while the LMTV can not, Alternatives 2 and 4 have marginally improved transportability when compared with the Baseline Fleet.

Finally, each Alternative requires about 1200 more personnel in the form of drivers and maintenance personnel than the Baseline Fleet.

6. CONCLUSIONS

The analysis has led to the following conclusions.

- It is feasible to eliminate the LMTV variant from the FMTV fleet by substituting 5/4-ton and MTV trucks and associated trailers.

- Because the LMTV mission and capability are well matched the preponderance of substitutions required an MTV; there were few opportunities to substitute smaller, less expensive vehicles. Thus, within the scope of the analysis, no alternatives exist which are less costly than the Baseline Fleet with equal capability.

- Several fleet alternatives exist with life cycle costs about 6% greater than the Baseline Fleet -- an amount not considered significant in cost estimating. These fleet alternatives have greater weight and cube capability (an assessment of the utility of this added payload capability was beyond the scope of this analysis) and somewhat enhanced mobility when compared with the Baseline Fleet.

- When the MTVs which are common to the Baseline and all alternative fleets are eliminated from the cost comparison, it is found that the LMTV substitute vehicles in the alternative fleets have a life cycle cost which is 20% greater than the life cycle cost of the LMTVs in the Baseline Fleet.

- Each of the feasible alternatives identified has shortcomings in the important areas of strategic deployability and personnel requirements.

- Each alternative fleet, when fully fielded, will increase sustainment costs about $30M per year when compared with the Baseline Fleet.

- Based on the factors considered in this analysis, no compelling rationale exists for the elimination of the LMTV variant from the FMTV family.

7. RECOMMENDATIONS

- The 2 1/2-ton truck should be retained in the Army force structure.

A TECHNICAL ASSESSMENT AND COST ANALYSIS OF THE STANDARD FINANCIAL SYSTEMS REDESIGN SUBSYSTEM 1 (SRD-1)

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U.S. Army Information Systems Command
Fort Huachuca, Arizona 85613

INTRODUCTION TO SRD-1.

SRD-1 is actually the first subsystem of the total Standard Financial Systems redesign effort. SRD-1 encompasses the functional financial areas of commercial accounts, disbursing, travel, military pay module, and central in/out processing. The second subsystem of the redesign effort is SRD-2 which is a redesign of the financial functions of Cost and General Accounting. The redesigned system is intended to replace the current Army financial system.

Why is a redesigned system required? Results by both in-house and contractor study groups indicated that the current Standard Army Financial System was lacking in several areas, including: noncompliance with GAO standards, system non-standardization, system non-responsiveness, and labor intensive manual input functions. Resolution of these deficiencies prompted the need for a system redesign.

PURPOSE OF THE ANALYSIS.

The study was performed to provide the sponsor, U.S. Army Finance and Accounting Center, with a cost and performance analysis of meticulously engineered system alternatives which would not only be cost effective but would also meet the functional as well as mandated legislative requirements of the SRD-1 subsystem.

OBJECTIVE & SCOPE OF THE ANALYSIS.

The primary objective, from an analytical standpoint, of the SRD-1 cost and performance analysis was to engineer and evaluate various network architectures which would best meet SRD-1 functional requirements and stated system objectives. The conclusion of this analysis would be the recommendation of a preferred alternative for deploying the SRD-1 system with deference given to the best cost/benefits ratio and ability to meet the overall SRD-1 system objectives.

The SRD-1 analysis was limited to forty-four CONUS ASIMS installation locations. (ASIMS is the Army Standard Information Management System; a common user processing utility for processing Army information systems in the sustaining base environment.) Transportability to other environments, including nonASIMS and OCONUS sites, was identified in the analysis of nonquantifiable factors. It was recommended that insights gained from the principal analysis be used to expand the study to address system deployment to Armywide locations in addition to the forty-four CONUS ASIMS sites. Furthermore, the study addressed five engineered alternatives for initial implementation of SRD-1 to the aforementioned ASIMS locations which describe processing and deployment scenarios of the system.

PRIMARY ASSUMPTIONS OF THE ANALYSIS.

1. The economic life of the STANFINS-Redesign Subsystem I project is 10 years.

2. Compatibility with other Army standard financial systems is an assumed requirement.

3. Economic life of all equipment, purchased or GFE, is 5 years.

4. Information provided by the functional proponent accurately depicts deployment schedules, system work loads, and functional system requirements.

THE PRINCIPAL LIMITATIONS.

Sizing data obtained via exercise of mathematical/simulation models is representative of true peak period requirements to plus or minus 33 percent. The relatively low level of precision stated is due to the macro level of detail that could reasonably be obtained for input to the modeling process, imprecision in the input data, computer capacity available for running the models, the degree of validation which could reasonably be accomplished, and the relative degree of precision required to project accurate costs.

Information provided for input into this analysis was collected from forty-four ASIMS CONUS installations. Assessments of projected systems performance outside the CONUS ASIMS or ASIMS-like processing locales could, therefore, not be considered with any degree of certainty.

Software requirements, both executive and applications, were considered to be equitable across all alternatives considered in this analysis.

ANALYSIS APPROACH & METHODOLOGY.

At the microlevel, a number of distinct techniques were used, ranging from simple itemization and cost apportionment models to engineering design and simulation. The major consideration given to this study was that of assuring comparability of the engineering alternatives considered.

Initially, prototype engineering designs were drafted and evaluated by the SRD-1 study team (Figure 1). Capacity evaluation for these engineered alternatives was made via analytical simulation models which were developed by the SRD-1 study team. This simulation and modeling effort used the SIMSCRIPT-based Network II.5 simulation package for personal computers to evaluate information processing, storage, and transfer performance within the projected SRD-1 systems environment (Figure 2). Considerable emphasis was placed on using the results of these analyses as a platform for projecting hardware requirements necessary to accommodate specific levels of processing intensity.

The alternative formulation was driven by the desire to cover the entire spectrum of Army Information Architecture (AIA) designs, to include solutions that distributed processing to all tiers of the Army's three tier information architecture in addition to one or two tier designs. Prototype engineering designs were subjected to capacity evaluation via analytical simulation models.

The costing process for conceptual systems required that generic equipment and software be identified to satisfy the architecture and that specific, but representative, equipment and software be assigned for costing purposes. Application software costs were estimated using a software engineering cost model, SECOMO (Figure 3). Timeframes for software completion were obtained and used to derive a hypothetical fielding schedule for life cycle cost estimating and derivation of deployment schedules.

Cost/Benefits analysis using the computer program Topographical Order Preference by Situation to the Ideal Solution (TOPSIS) was performed across all alternatives resulting in an alternative preference ranking (Figure 4). The TOPSIS program was used in an effort to reduce undue bias which might impress more favorable attribute (nonquantifiable benefit) ratings upon a decision makers preferred alternative. Following determination of the TOPSIS derived attribute ratings, the discounted Uniform Annual Cost (UAC) for each alternative was compared to the benefit ranking in order to establish a composite preference order of alternatives; thus yielding a preferred alternative.

THE PRINCIPAL FINDINGS

Networked system architectures, modeling efforts, and analytical cost methodologies developed and utilized within this study have provided the most economical and efficient means for implementing an interactive, Standard Army Financial System (STANFINS) network within the Army's financial functions of travel, commercial accounts, disbursing and military in/out processing. The principal findings of this cost and performance analysis indicate that the preferred design for meeting SRD-1 system functionality and cost effectiveness would be performing the required data processing at the Regional Data Centers (RDCs-Tier 1) with data input occurring at the functional module level (Tier 3). Within this operating context, the installation Data Processing Centers (DPCs-Tier 2) would predominately be used as a communications gateway to the ASIMS network.

One of the alternatives considered, which was initially preferred by the command's management hierarchy, was conceptually the same as the preferred alternative with the exception of the data processing requirement. Within the scope of this alternative, the data processing would be performed at the installation DPC (Tier 2) facilities. Results from the Information Process Facility (IPF) study, conducted by the SRD-1 study team, have shown that there is an insufficient amount of processing, storage and printing resources available at Army DPCs as well as the Army Data Processing Installations

(DPIs). Based on the hardware, software, and personnel requirements determined technically necessary to deploy such a system, the cost/benefits assessment proved this alternative prohibitive from further consideration.

Two of the alternatives utilized a distributed database approach with the processing occurring at both the installation DPCs (Tier 2) and the functional module level (Tier 3). A simulation and modeling analysis of this approach was run using SIMSCRIPT-based NETWORK II.5. Results of this analysis yielded conclusively that for these alternatives to remain competitive with other alternatives from a cost/benefit perspective, the designated hardware capabilities would be saturated by processing requirements. Based on this capacity analysis, these alternatives were discounted from further consideration.

The last alternative considered was designed for distributed database processing restricted to the functional module level (Tier 3). Again, a modeling and simulation analysis was performed to project processing capacity operations. Although analysis of this alternative yielded somewhat favorable results in terms of retaining all processing at the Tier 3 level, the cost/benefits associated with transitioning from strictly RDC to functional user level processing resulted in unfavorable consideration of this approach. Initiatives to evolve the preferred alternative from a Tier 1 to Tier 3 mode of operation should be sought to provide a more functionally applicable and available system operation to user-intensive levels at the installation finance and accounting offices.

In light of SRD-1 requirements, and major efforts and analyses leading to a selection of a preferred alternative, (uniform annual cost; cost/benefits; software cost modeling; simulation modeling; and capacity planning), the findings of this cost and performance analysis indicate that efforts originally begun to implement an interactive standard financial system from RDC level processing (Tier 1) to functional user level processing (Tier 3) should continue as is being done.

Because of the various software development completion periods between alternatives, receipt of benefits for each alternative required that a uniform annual cost be used in determining the most appropriate scale of economy.

Thorough data analysis of the five Army RDCs has shown that the current STANFINS system is by far the largest user of available mainframe processing and storage resources.

STUDY IMPACT.

The study enabled the SRD-1 system proponent to successfully gain DA approval to begin deployment of the preferred system alternative.

The results and insights gained from this analysis, along with the analytical tools developed therein, are currently being used in other financial system redesign analyses.

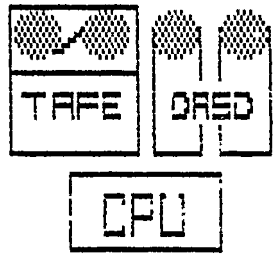
SRD-1 PROTOTYPE ENGINEERING DESIGNS CONSIDERED

ALTERNATIVE 1

TIER 1: DATA PROCESSING AT REGIONAL DATA CENTERS

TIER 2: INSTALLATION DPCs AS COMMUNICATIONS GATEWAY

TIER 3: DATA ENTRY AT FUNCTIONAL USER LEVEL



ALTERNATIVE 2

TIER 1: EXTERNAL SYSTEM INTERFACING AT REGIONAL DATA CENTERS

TIER 2: DATA PROCESSING AT INSTALLATION DPCs

TIER 3: DATA ENTRY AT FUNCTIONAL USER LEVEL

ALTERNATIVE 3

TIER 1: EXTERNAL SYSTEM INTERFACING AT REGIONAL DATA CENTERS

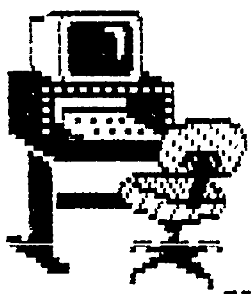
TIER 2: DATA PROCESSING AT INSTALLATION DPCs WITH DISTRIBUTED PROCESSING AT TIER 3 INSTALLATION LEVEL

TIER 3: DATA ENTRY AT FUNCTIONAL USER LEVEL (PC - LOCAL AREA NETWORK CONFIGURATION)

ALTERNATIVE 4

TIER 1: EXTERNAL SYSTEM INTERFACING AT REGIONAL DATA CENTERS

TIER 2: DATA PROCESSING AT INSTALLATION DPC WITH DISTRIBUTED PROCESSING AT TIER 3 INSTALLATION LEVEL



TIER 3: DATA ENTRY AT FUNCTIONAL USER LEVEL (PC - FILE SERVER CONFIGURATION)

ALTERNATIVE 5

TIER 1: EXTERNAL SYSTEM INTERFACING AT RDCs

TIER 2: INSTALLATION DPCs AS COMMUNICATIONS GATEWAY

TIER 3: DATA ENTRY AND DATA PROCESSING AT FUNCTIONAL USER LEVEL

(FIGURE 1)

<u>SYSTEM CAPACITY ESTIMATE USING NETWORK II.5 SIMULATION PACKAGE</u>

THIS EXAMPLE REFERS TO ALTERNATIVE 5 OF THE ANALYSIS

TRANSFER DEVICE SIMULATING AN IEEE 802.3 LOCAL AREA NETWORK (LAN)

(PERSONAL COMPUTER - FILE SERVER CONFIGURATION)

STATISTICAL DISTRIBUTIONS CONSTRUCTED USING:

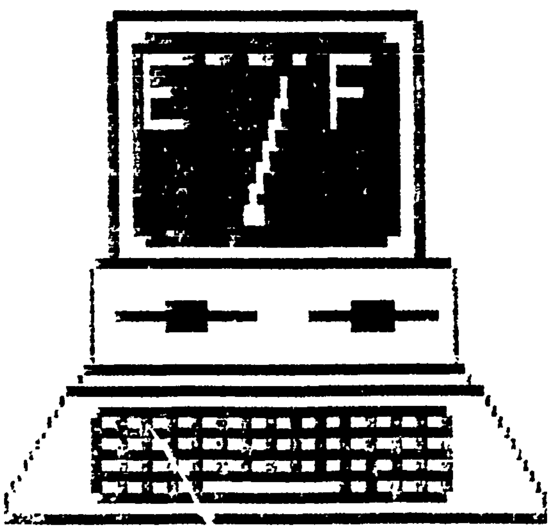
--IEEE BACKOFF ALGORITHM USED IN 802.3 NETWORK FOR 10MBPS LAN

--VARIABLE FILE LENGTHS FOR DATA BASE UPDATES TO FILE SERVER

--WORKSTATION MACHINE CYCLE REQUIREMENTS PER PROCESSING JOB

FILE SERVER UTILIZATION BASED ON STEADY-STATE 8 HOUR PERIODS

--FILE SERVER UTILIZATION RANGED FROM 11.5% - 42.9% (9 PCs USED)



(FIGURE 2)

SOFTWARE COST ESTIMATION USING SECOMO MODEL

ESTABLISH PARAMETERS FOR SECOMO MODEL

--TOTAL PROGRAM SIZE

--PERCENTAGE OF PROGRAM REQUIRING MODIFICATION/DEVELOPMENT

--PROGRAM ANALYST CAPABILITIES, KNOWLEDGE, & EXPERIENCE

MODEL RUN TO ESTABLISH DEVELOPMENT COST & ANNUAL MAINTENANCE

SENSITIVITY ANALYSIS

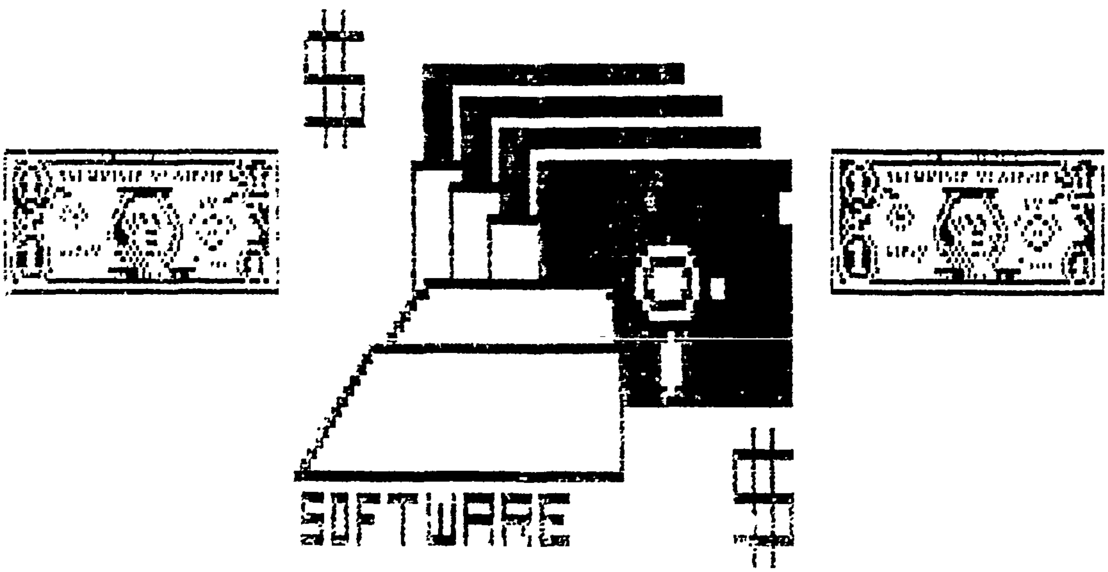
--15 VARIATIONS OF INITIAL PARAMETERS

--PERCENTAGE OF OVERALL DESIGN MODIFICATION

--PERCENTAGE OF CODE MODIFICATION

--INTEGRATION EFFORT REQUIRED DUE TO MODIFICATION

CONSIDERED MONTHS REQUIRED FOR DEVELOPMENT



(FIGURE 3)

COST/BENEFIT ANALYSIS USING TOPSIS MODEL

RANK NON-QUANTIFIABLE BENEFITS ACROSS ALTERNATIVES

--INPUT DATA INTO TOPSIS (TOPOGRAPHICAL ORDER PREFERENCE BY SITUATION TO THE IDEAL SOLUTION)

--INPUT UNIFORM ANNUAL COST FOR ALTERNATIVES AS MINIMIZATION FUNCTION

TOPSIS DETERMINES (FROM INPUT DATA):

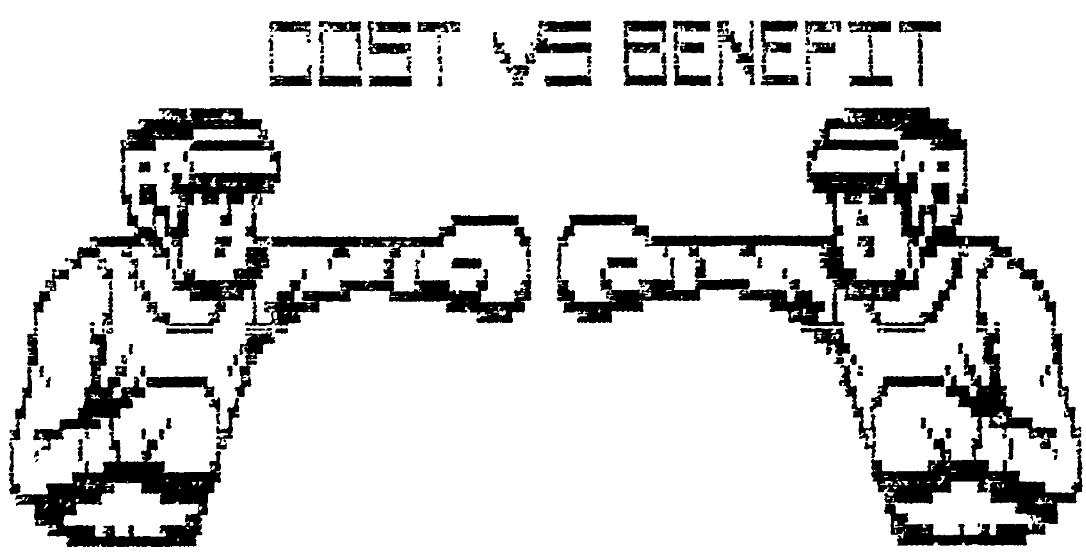
--DECISION MATRIX

--EIGENVECTOR PAIRWISE COMPARISON

--DECISION MAKER SUBJECTIVE WEIGHTS

--IDEAL & NEGATIVE-IDEAL SOLUTIONS

--PREFERRED RANKING OF ALTERNATIVES



(FIGURE 4)

#119

TITLE: A Field Investigation for the Detectability of Surface-Laid Mines

AUTHOR: D. D. Gascoyne

ORGANIZATION: Indirect Fire Studies Division
Royal Armament Research and Development Establishment
Fort Halstead, Sevenoaks, Kent, TN14 7BP

ABSTRACT:

NATO and WP forces are bringing scatterable mine (SM) systems into Service, to kill, divert, or delay enemy armour. The effectiveness of SM will depend largely on the ability of individual vehicles to detect their presence. Sensors capable of recognizing SM at safe distances are likely to require lines-of-sight.

A field experimental techniques is described, for determining the occurrence of lines-of-sight, between surface laid mines in various vegetation environments and sensors mounted at a tank driver's eye height. An initial series of trials involving over 124,000 measurements is described and the results are discussed. The need to verify current assumptions regarding the types and relative areas of vegetation within 1(BR)Corps area is identified, and the use of satellite imaging is proposed.

PAPER IS CLASSIFIED
REQUESTS FOR INFORMATION SHOULD
BE DIRECTED TO ORIGINATING AGENCY

ENHANCING MINE WARFARE IN VECTOR-IN-COMMANDER

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ABSTRACT

As part of an ongoing research effort to enhance the representation of natural and man-made obstacles in the U.S. Army corps-level combat simulation model, Vector-In-Commander (VIC), an investigation into the minefield attrition and delay methodologies has been conducted. A high-resolution mine/countermine model capable of playing direct cover fire was used to qualitatively validate the minefield attrition and delay methodologies in VIC. The results of the validation effort are presented along with a detailed analysis of the current methodologies and specific recommendations as to how minefield play in VIC can be improved.

INTRODUCTION

In 1979, the Review of Army Analysis (Reference 1) found several deficiencies in the Army's computerized combat models: poor documentation, poor response to study needs, inconsistent results, differing data assumptions, lack of interface structure, and limited (or no) functional area representation. Thus, in April 1980, a directive was implemented for an Army Model Improvement Program (AMIP). The tasks and responsibilities of AMIP are described in Army Regulation (AR) 5-11.

The Engineer Model Improvement Program (EMIP) is a part of AMIP designed to ensure that engineers are properly represented in the Army's hierarchy of combat simulation models (Figure 1) and was published by the Engineer Studies Center in 1988 (Reference 2). Priority was placed on enhancements to VIC and the development of a VIC-based Engineer Functional Area Model (hereafter referred to as VIC-EFAM).

Under EMIP, the U.S. Army Engineer Waterways Experiment Station (WES) was tasked to conduct unit maneuver research. One of the items to be addressed under unit maneuver research is whether mine warfare is correctly represented in the model. This paper addresses this issue. Specifically, a detailed analysis of the algorithms and logic used in the reference version of VIC is presented along with results from a high resolution minefield model (References 3 and 4) that was used to validate some of those algorithms. Specific recommendations are made for improving the existing methodologies. The improved methodologies will be used in the VIC-EFAM and submitted for acceptance into the reference version of VIC.

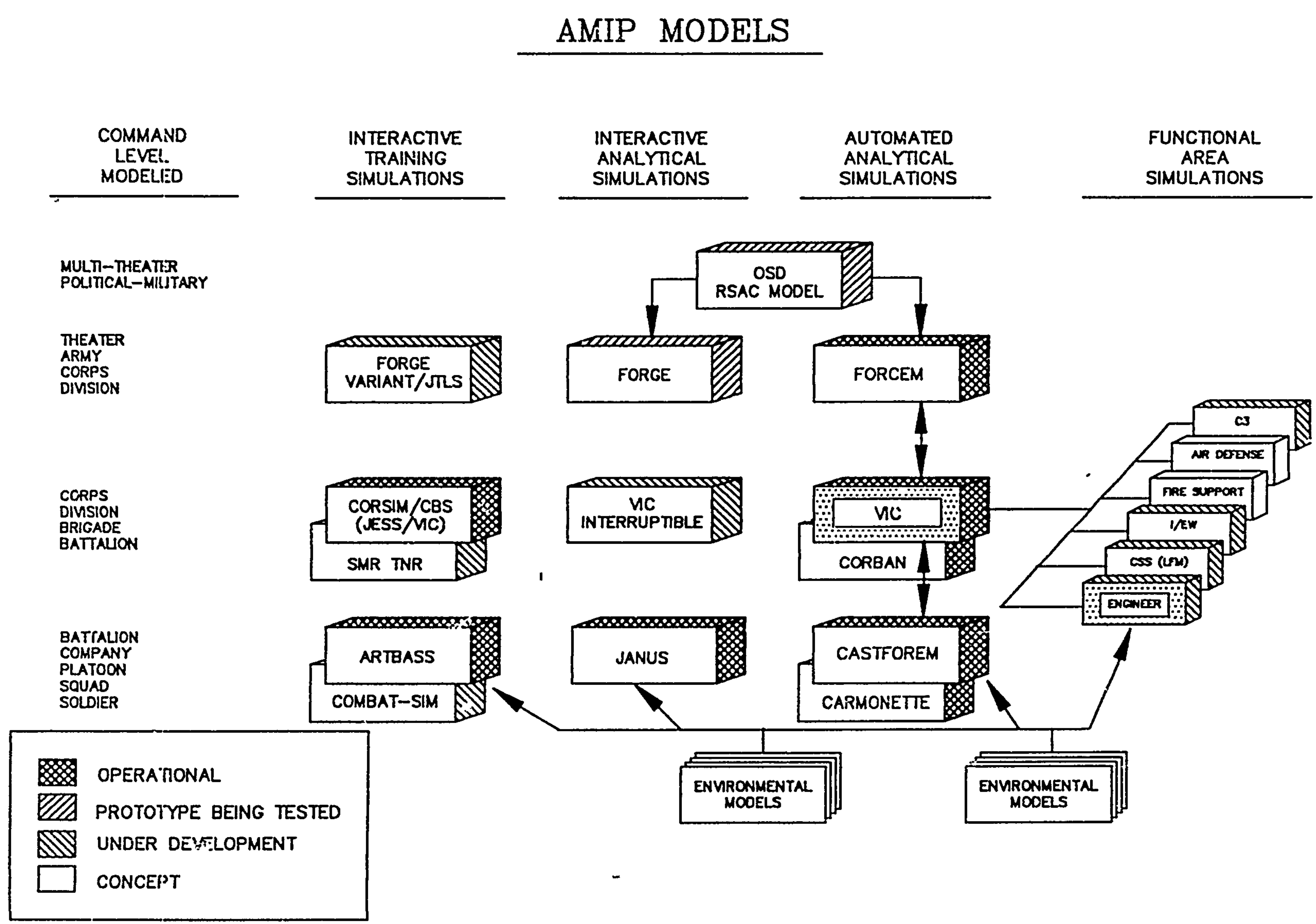

Figure 1. Army Model Improvement Program hierarchy of combat simulation models.

OVERVIEW OF VIC

"VIC is a two-sided deterministic simulation of combat in a combined arms environment. The model is designed to provide a balanced representation of the major force elements in a tactical campaign of a U.S. Army corps operating in a theater of operations. It represents friendly air and land forces and a commensurate enemy force in a mid-intensity battle. The model is event stepped for maneuver elements and time stepped for support elements. Maneuver units initially move along scripted paths. Decision tables exercise command and control in the automated simulation" (Reference 5).

VIC is considered a heterogeneous aggregated model, with each aggregated unit maintaining a count of the number of surviving weapon systems of each distinct type. In VIC, the aggregated units are modeled as circles for most calculations. VIC utilizes a regular grid system to overlay a map of the battlefield. Terrain is input to grid squares by parameters that reflect the trafficability and intervisibility for each grid cell. Natural and man-made linear obstacles (escarpments, rivers, and tank ditches) are represented by line segments which are independent of the grid cells. Natural and man-made area obstacles (urban areas, large bodies of water, swamps, contaminated areas, etc.) are represented by polygons which are also independent of the grid cells.

Minefields are treated as point obstacles and can be pre-emplaced, emplaced at a specified time during the game, emplaced by engineers at a specified time, emplaced by engineers in a hasty defense, artillery-delivered at a specified time, and artillery delivered in a hasty defense. To minimize the input data needed to define a scenario, minefield prototypes are established. Factors such as mine type, density, lethality, and intended target type (infantry, armor, or both) are specified for each mine prototype. The actual minefields are then specified as to prototype, location, size, and emplacement time. When a maneuver unit hits a minefield, attrition and a static delay are assessed at the point of encounter based on the user input for that minefield's prototype.

CURRENT MINEFIELD PLAY IN VIC

Three minefield tactics are currently played in VIC: "clear" (i.e., breach in stride), bull, and bypass. The minefield tactic to be employed is an input quantity which varies as a function of the combat status of the unit hitting the minefield.

The flow chart shown in Figure 2 demonstrates the methodology used in VIC to assess minefield attrition and delay. Upon encountering a minefield, a ground unit will suffer initial losses before the discovery becomes apparent. After the discovery is made, the ground unit is delayed while a decision is made on the tactics to adopt and while those tactics are set in motion. (For example, if the tactic is to breach using plows and rollers, time may be required to move those assets forward to the edge of the minefield.) If a decision is made to breach or bull-through, additional delays are suffered while one or more lanes are cleared (the clearing delays) and while the rest of the unit is negotiated through the breach lanes (the crossing delays). Additional losses are also suffered in the process of clearing and crossing

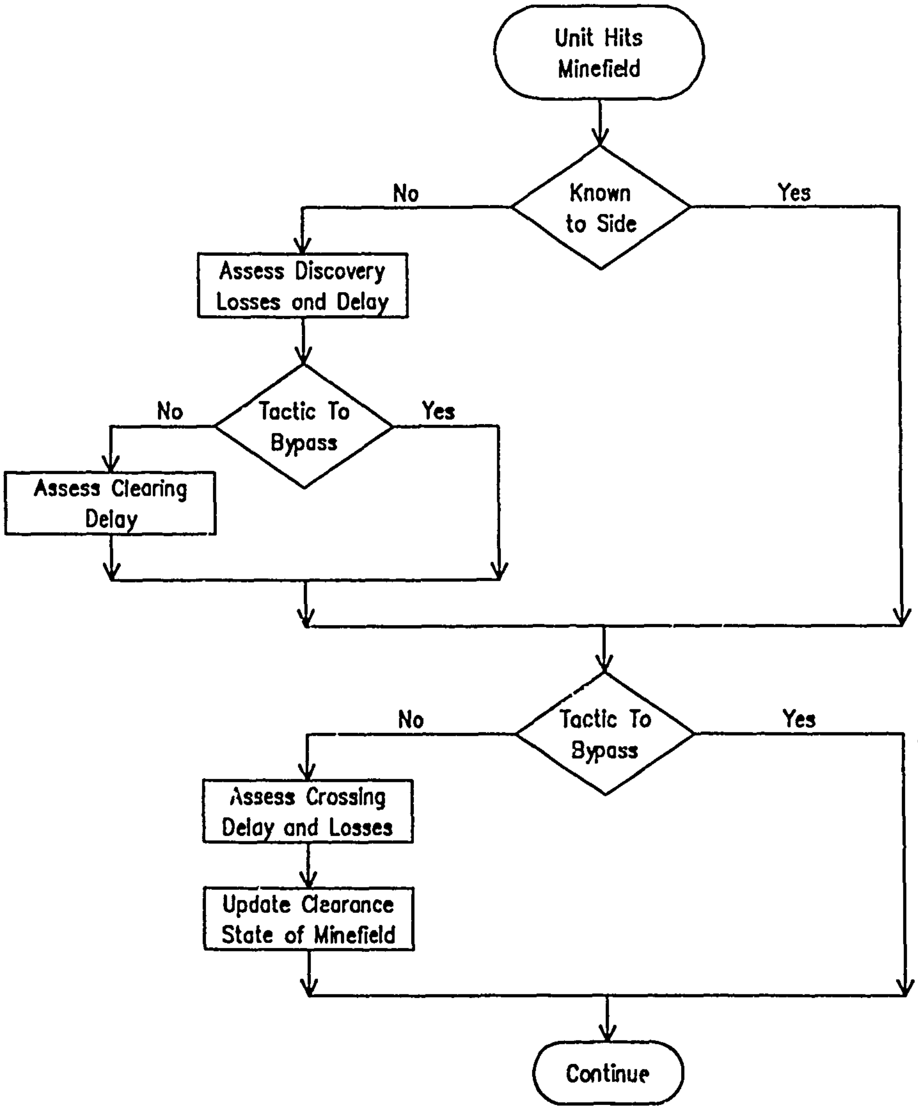

Figure 2. Existing minefield methodology in VIC.

the minefield. These losses are lumped under the term "crossing losses". Note that all units on the side that emplaced the minefield are assumed to know where the minefield is and, once the minefield has been discovered by a unit on the opposing side, its presence is assumed to be known by all units on the opposing side as well. Discovery losses and delays are therefore only calculated for the first opposing unit to hit the minefield. Likewise, breaching delays are only assessed for the first unit encountering the minefield under the assumption that previous encounters would have resulted in breach lanes being formed.

The discovery delay is an input value which varies as a function of the minefield prototype and the minefield tactic employed. For a tactic of bypass, clearing and crossing delays are not computed and, instead, the input discovery delay is supposed to include the delay suffered while circumnavigating the minefield. If the tactic is to breach or bull through, clearing and crossing delays are calculated as follows:

$$\text{Clearing Delay} = \frac{\text{Minefield Depth}}{\text{Breaching Speed}} \tag{1}$$

$$\text{Crossing Delay} = \frac{\text{Minefield Depth} + \text{Unit Diameter}}{\text{Crossing Speed}} - \frac{\text{Minefield Depth} + \text{Unit Diameter}}{\text{Unimpaired Speed}} \tag{2}$$

where the breaching and crossing speeds are also input values which vary as a function of the minefield prototype and the minefield tactic employed and the unimpaired speed is the speed at which the unit was moving before it encountered the minefield.

The total delay is computed by summing the three components of delay and multiplying the result by the fraction of mines still remaining in the minefield when it was hit:

$$\text{Total Delay} = (\text{Discovery} + \text{Clearing} + \text{Crossing}) * (1\text{-Fraction Cleared}) \tag{3}$$

The fraction cleared is adjusted each time a minefield is crossed using an input quantity specifying the fraction cleared per unit passage. In this manner, the delay times account for any existing breach lanes (from prior unit encounters), and subsequent improvements to those breach lanes over time. Note that since discovery delay is only assessed to the first unit encountering the minefield, it is always zero when the fraction cleared is nonzero. Equation 3 could just as easily have been written as

$$\text{Total Delay} = \text{Discovery} + \text{Clearing} + \text{Crossing} * (1\text{-Fraction Cleared}) \tag{4}$$

Equations 3 and 4 express the total delay suffered by the sub-unit negotiating the minefield (e.g., one company within a battalion-sized unit). The assessed delay (i.e., the delay suffered by the entire battalion) is obtained by multiplying the total delay above by the geometric fraction of the unit in the minefield:

$$\text{Assessed Delay} = \text{Total Delay} * \frac{\text{Minefield Frontage}}{\text{Unit Diameter}} \qquad (5)$$

Minefield losses are based on the number of vehicle columns entering the minefield. This is computed by multiplying the number of leading columns in the unit's formation (based on input values for both opposed and unopposed movement of each minefield-attritable unit) by the fraction of the unit exposed to the minefield (as shown in Figure 3). In calculating the fraction of the unit in the minefield, it is assumed that the minefield is always oriented perpendicular to the unit's line of advance.

Minefield losses can be calculated in either an aggregated or detailed fashion. Detailed attrition involves an accounting of each individual weapon system within a unit whereas aggregated attrition is based on the overall mass of a unit (expressed in terms of tank equivalents).

If aggregated attrition is being played, each unit has a discovery loss rate (input as a mass loss per vehicle column) and crossing loss rates for both the breaching and bulling tactics (input as a mass loss per vehicle column per unit linear minefield density) for each of the minefield prototypes being played. The discovery loss rate is multiplied by the number of vehicle columns in the minefield to arrive at a mass loss due to discovery and the crossing loss rate is multiplied by the number of vehicle columns in the minefield and the linear density of the minefield to arrive at a mass loss suffered in crossing.

If detailed attrition is being played, each of the unit's weapon systems has a discovery loss rate (input as the number of weapons lost per vehicle column) and crossing loss rates for both the breaching and bulling tactics (input as the number of weapons lost per vehicle column per unit linear minefield density) for each of the minefield prototypes being played. Discovery losses are computed for each weapon type by multiplying the discovery loss rate by the number of columns hitting the minefield. Crossing losses are computed by multiplying the appropriate crossing loss rate by the number of columns hitting the minefield and the linear density of the minefield.

Referring to Figure 3, only those weapon systems in the front aspect of the unit circle are attrited. Usually those weapons which "move and shoot" (i.e., tanks, infantry fighting vehicles, etc.) are located in the front aspect. Also, only those weapon systems designated in the input as minefield attritable can be lost in the minefield. This is done to prevent weapons such as helicopters from being attrited by mines. Lastly, weapons that are mounted on a platform (i.e., soldiers riding on a truck) can only be attrited if their platform is attrited.

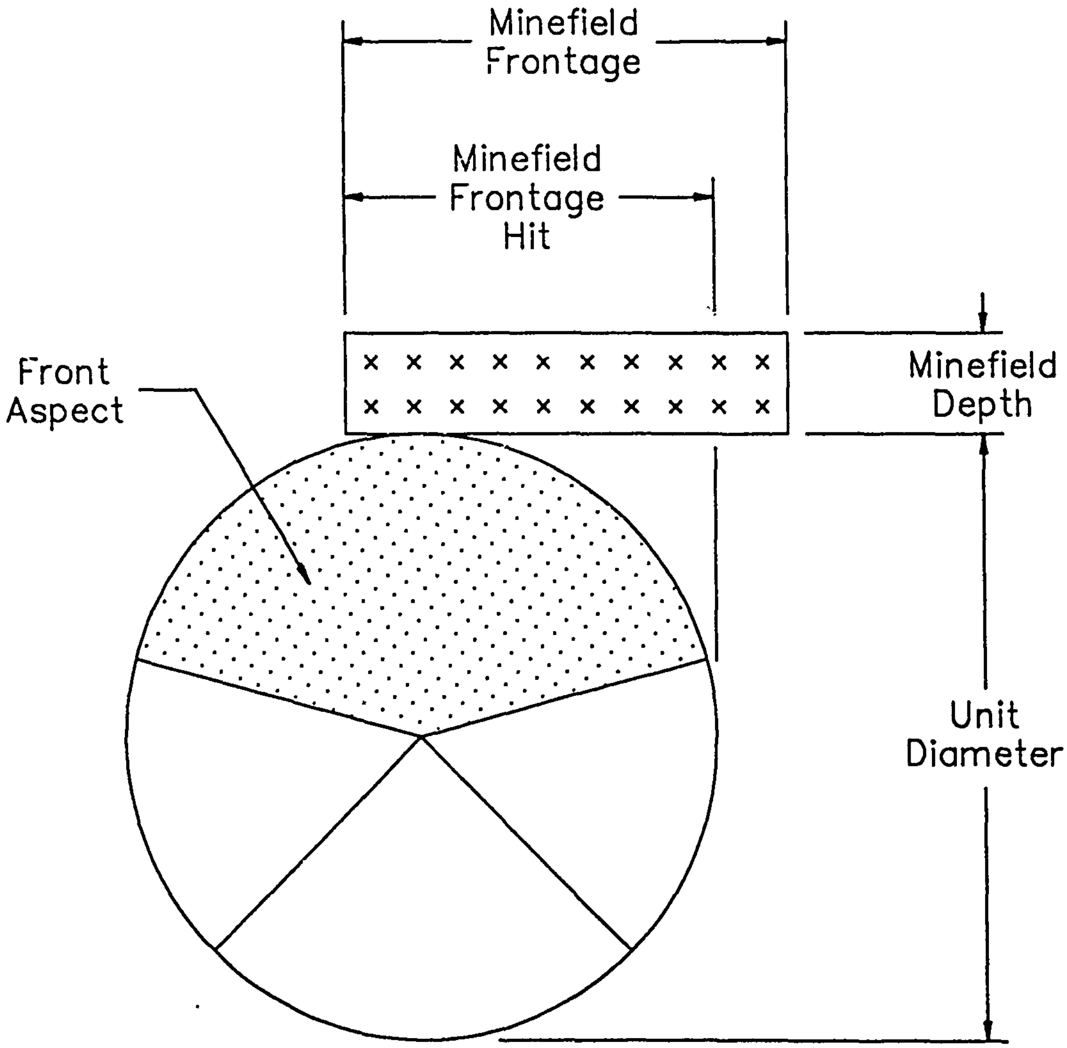

Figure 3. Fraction of unit in minefield calculation.

PROBLEMS WITH EXISTING METHODOLOGY

Numerous problems exist with the algorithms and methodology for calculating minefield attrition and delay. Some of the deficiencies are as follows:

a. There is no way to emplace a minefield in VIC so that it cannot be bypassed, because the decision to bypass is based purely on the encountering unit's combat status. In reality, minefields designed to fix or block the enemy are often emplaced in such a manner that bypass is difficult, if not impossible.

b. The minefield logic assumes that units never have to breach minefields emplaced by their own side where, in fact, breach lanes may not be available (or clearly marked) in artillery-delivered minefields. The minefield logic also assumes that a previously encountered minefield will have breach lanes through it. This ignores the possibility that the unit first encountering the minefield bypassed it.

c. For a tactic of "bypass," the discovery delay, which includes the bypass delay, is a function solely of minefield prototype and is therefore independent of the size of the unit encountering the minefield, the size of the minefield itself, and the trafficability of the surrounding terrain.

d. The fraction of the unit in the minefield is calculated using a strictly geometric relationship between the minefield frontage and the unit diameter. This ignores the fact that the ground unit is actually composed of a relatively small number of essentially inseparable sub-units (e.g., the companies in a battalion). If any portion of a sub-unit gets stuck in a minefield, the entire sub-unit is generally delayed. Therefore, the code severely underestimates the attrition and delay suffered by the ground unit.

e. Crossing losses are assumed to be directly proportional to the linear density of the minefield.

f. The crossing losses are taken to be directly proportional to the geometric fraction of the unit in the minefield. The fraction of the unit in the minefield is multiplied by the number of leading vehicle columns to obtain the number of vehicle columns crossing the minefield. Because these calculations are performed using real, rather than integer, arithmetic, one often sees tenths of a column crossing the minefield.

g. Contrary to doctrine, minefields are not covered by either direct or indirect fire. This ignores the primary purpose of minefields, which is to slow or redirect a unit so as to increase its vulnerability to fire.

QUALITATIVE VALIDATION OF CROSSING LOSS CALCULATIONS

It is generally recognized that minefield attrition does not vary in direct proportion to linear (or for that matter areal) density. To investigate the form of a mathematical relationship between attrition and linear density, a stochastically-based, high-resolution mine/countermine model (Reference 3) was used. The basic scenario consisted of four armor-pure companies attacking on separate avenues of approach against an objective defended by a company-sized unit. Each avenue of approach contained a single 500 by 150 meter minefield. Each company was equipped with one track-width mine plow and one track-width mine roller. Calculations were performed with four different linear densities: 0.375, 0.75, 1.5, and 3.0 mines per meter of frontage. The resulting crossing losses are shown in Figure 4. As is evident in this figure, a doubling of the mine density produces significantly less than twice the number of losses.

PROPOSED ENHANCEMENTS TO MINEFIELD PLAY

In this section, specific recommendations will be made to correct the deficiencies previously noted. These will be addressed individually in the same order as they were presented in that section.

a. To allow minefields to be emplaced so as to prevent a bypass, it is suggested that units only be allowed to bypass minefields if the trafficability (based on vegetation and relief) in the vicinity of the minefield is fair or better. This assumes that in rugged areas or areas having dense vegetation, the minefields have been tied into the surrounding terrain; therefore, bypass is not a viable option. If the unit's minefield tactic (based on its combat status) was to bypass, the unit is made to breach the minefield.

b. To better represent the effects of artillery-delivered minefields on friendly forces, units encountering a friendly, artillery-delivered minefield should be assessed a clearing delay and clearing/crossing losses in addition to the crossing delay already assessed. In addition, breaching delays should be assessed, regardless of discovery status, if the fraction cleared is still zero.

c. To account for the effects of minefield size and trafficability on bypass delay, it is suggested that the bypass delay be removed from the input discovery delay and, instead, calculated according to the concepts shown in Figure 5. Aggregating the fraction of the unit hitting the minefield into a sub-unit whose diameter is equal to the minefield frontage hit, simple paths around the minefield can be calculated. Assuming perfect knowledge, the shorter of the two paths is chosen as the bypass route. The bypass delay is calculated based on the length of this route and the unit's rate of advance. The latter automatically takes relief, vegetation, and opposition into account.

The changes above are summarized by the enhanced minefield logic shown in Figure 6.

d. Presently, the fraction of the unit in the minefield is calculated using a strictly geometrical relationship between the minefield frontage and the unit diameter that ignores the internal structure of the aggregated unit. Taking the example of a battalion deployed across a 6-km sector, a 500-m minefield would block 1/12 of the battalion based upon geometry alone. In general, however, minefields can be expected to block the avenue of approach of at least one company, and even if the entire company did not enter the minefield, it would still stop until the platoon stuck in the minefield

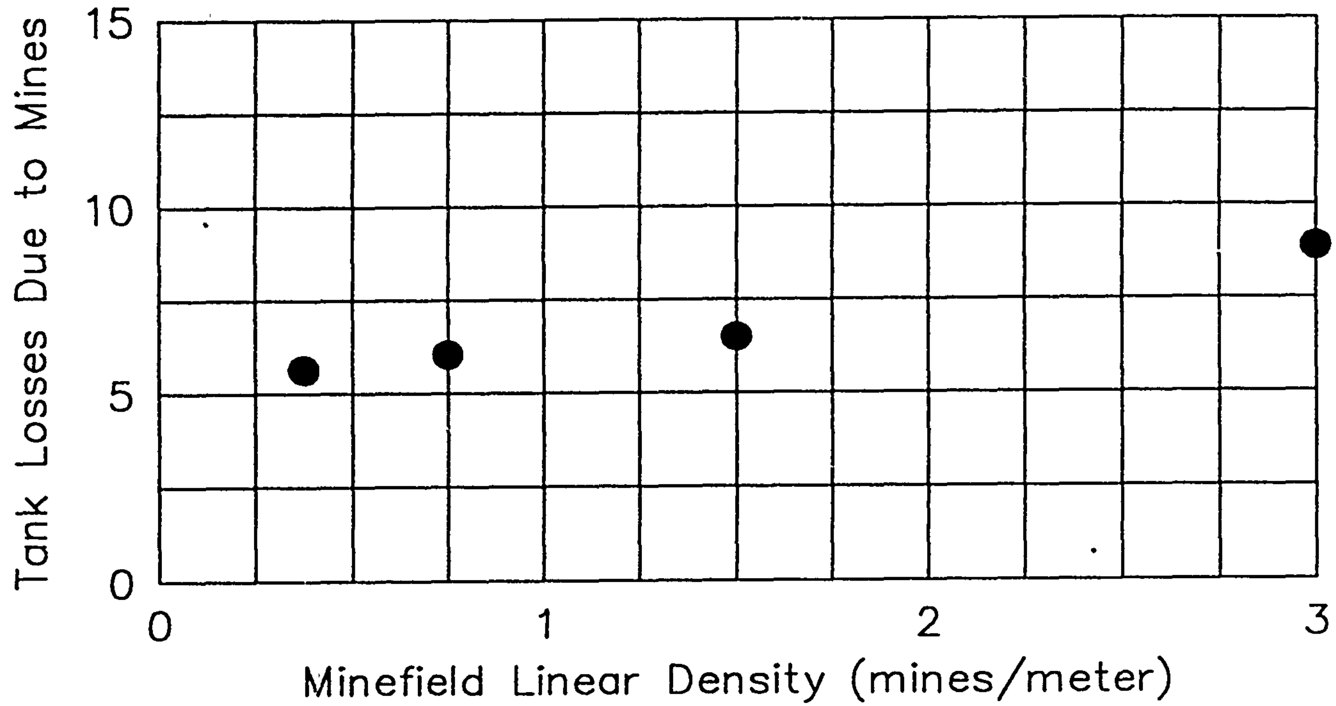

Figure 4. Tank losses due to mines as a function of minefield linear density.

Bypass Delay = 2 * min(a,b) / Unit Speed

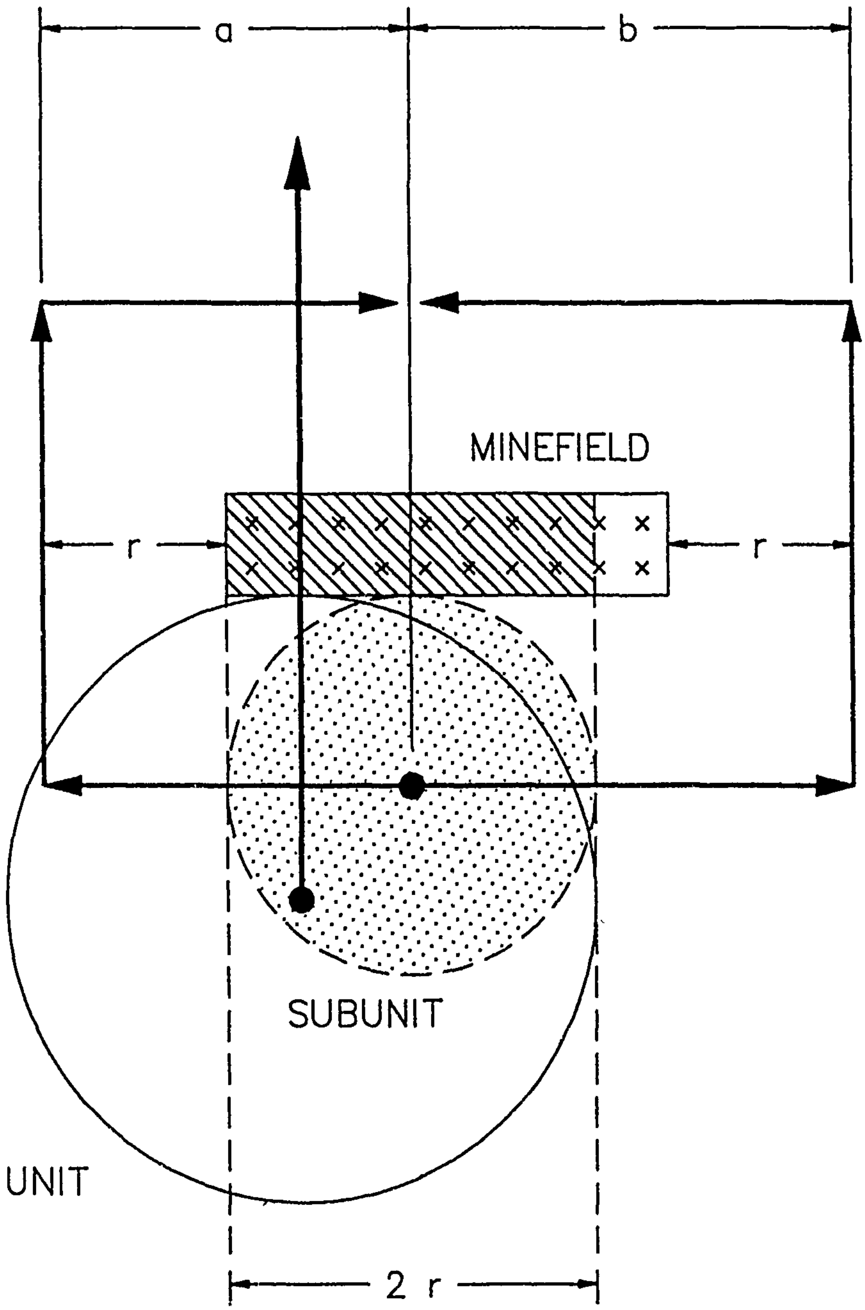

Figure 5. Proposed bypass delay calculations.

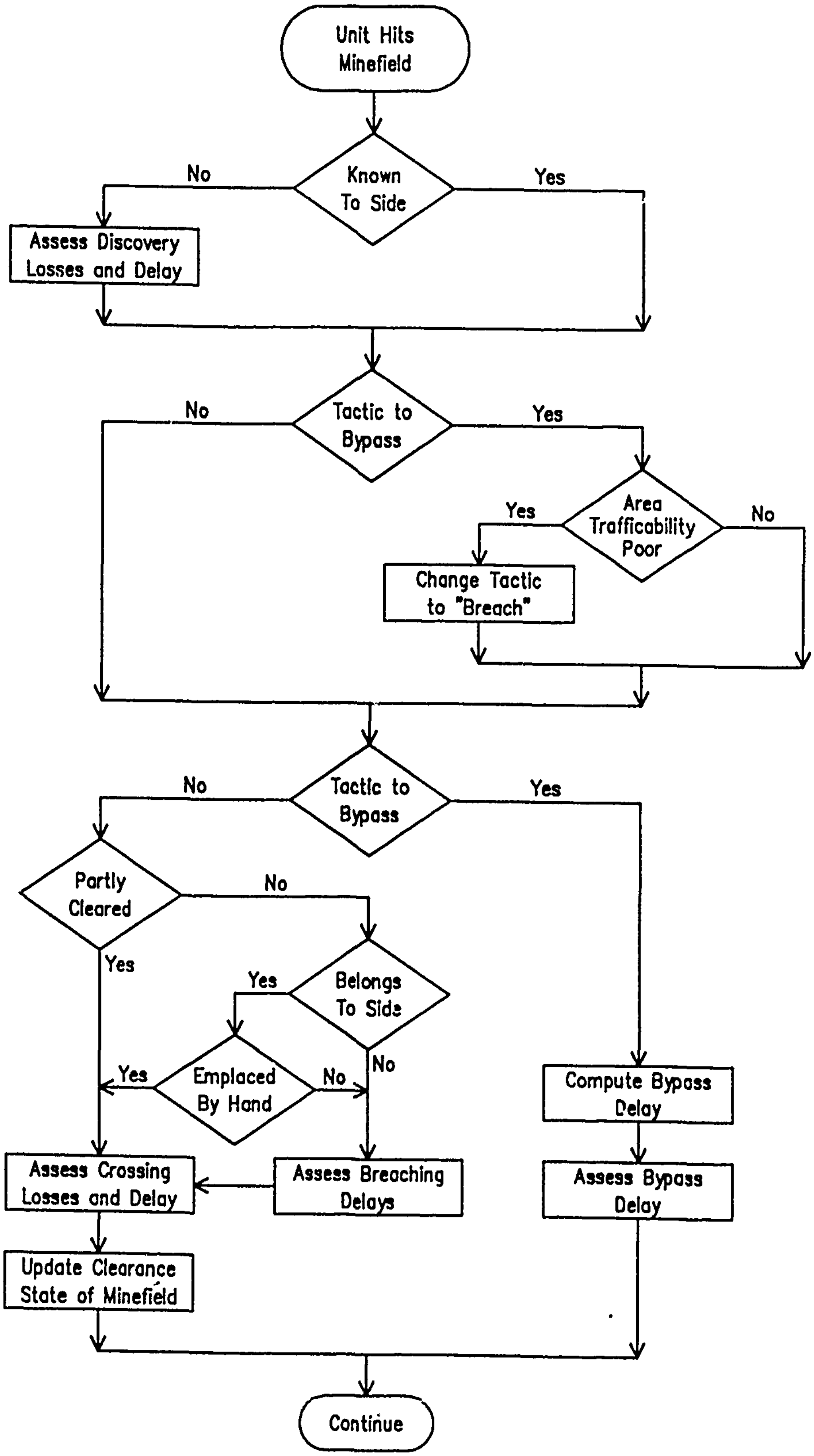

Figure 6. Enhanced minefield logic for VIC.

extricated themselves. After all, minefield breaching is practiced at the company level, not the platoon level. Therefore, the fraction of the unit in the minefield should be calculated by determining the integer number of companies affected by the minefield. Since a battalion would seldom contain more than 6 companies (including any direct support elements) the actual fraction of the unit in the minefield would be no less than 1/6, which is twice the amount computed by geometry alone. This enhancement can be accomplished by inputting the number of companies leading when opposed and unopposed for the respective unit prototypes. The geometric fraction of the unit can then be multiplied by the number of leading companies and rounded accordingly.

e. It is suggested that additional studies be performed using historical data and/or high-resolution mine/countermine models to determine a more accurate relationship between crossing losses and minefield linear density.

f. To resolve the problem of fractional vehicle columns, it must be assumed that an integer number of vehicle columns will cross the minefield; therefore, the attrition algorithms should be changed to round the number of columns to the next higher integer. While this may seem to be a fairly minor adjustment, the difference between a few tenths of a vehicle column and an entire vehicle column results in a doubling or tripling of the minefield attrition (typically, only two to three percent of the attrition in a given scenario results from minefield encounters as opposed to historical averages of ten or twelve percent), this seemingly minor change should bring the scenario results more into line with the historical averages.

g. As a starting point for addressing the problem of cover fire on minefields, it can be assumed that any minefield located within a certain distance of the Forward Edge of the Battle Area (FEBA) is automatically covered by indirect and/or direct fire. It is a relatively simple matter to generate a call for indirect fire whenever a unit encounters such minefield; however, to decrease run time, VIC only assigns artillery missions at prescribed intervals (typically 15-minutes). Because the delay assessed the aggregated ground unit is only a fraction of the actual delay (being scaled by the fraction of the unit in the minefield), it would be highly likely that the unit will have left the minefield by the time the artillery is delivered. A possible solution to this problem is to assign artillery missions on demand; however, detailed studies are needed to determine the effect this would have on run time.

The problem of direct fire is much harder to address due to the level of aggregation played in VIC. Due to memory and run time constraints, it would be infeasible to explicitly play direct cover fire by creating platoon- and/or company-sized ground units to cover every minefield. The only alternative is to implicitly play cover fire. Increasing the lethality of minefields located within the prescribed distance of the FEBA would be one way to accomplish this but would only account for the direct-fire attrition of the unit encountering the minefield without addressing the friendly losses incurred due to return fire. Furthermore, it would be difficult to come up with attrition coefficients that properly represent the synergistic effects of cover fire on minefields. Clearly, much more study is needed in this area.

SUMMARY

A brief overview of minefield play in VIC has been presented. Six areas have been identified in which improvements to minefield play can be made while maintaining the intended l   of aggregation within VIC. Algorithms have been formulated and coded   minefields to be tied into the terrain, to better represent the effe   artillery-delivered minefields on friendly forces, to take terrain and minefield size into account when assessing bypass delay, to better determine the crossing losses based on minefield density, and to more realistically calculate the attrition and delay assessed the aggregated units in VIC. Additional recommendations have also been presented as a starting point for playing minefield cover fire in VIC.

ACKNOWLEDGMENT

The work and resulting data described herein, unless otherwise noted, were obtained from research conducted under the MILITARY RESEARCH DEVELOPMENT TEST AND EVALUATION PROGRAM of the United States Army Corps of Engineers by the U.S. Army Engineer Waterways Experiment Station and were part of DA Project AT40/AM/002, under "Validation and Verification of VIC-EFAM Enhancements," and the Army Model Management Office, under Appropriation No. 2192040 08-1706 P612784.T40 S22079, entitled "FAM Development." Permission was granted by the Chief of Engineers to publish this information.

Responsibility for coordinating the EMIP program at WES was assigned to Mr. Tommy C. Dean of the Mobility Systems Division (MSD), Geotechnical Laboratory (GL), under the general direction of Mr. Newell R. Murphy, Chief, MSD, and Dr. William F. Marcuson III, Chief, GL. Dr. Paul F. Hadala, Assistant Chief, GL, is the Corps of Engineers, R&D program coordinator for EMIP.

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start and goal locations as shown in Figures 3 and 4. When h* equals 0, A* may also be reduced to a blind search referred to as a uniform-cost search (Pearl 1984). The uniform-cost search does not require the OPEN and CLOSED lists to be checked before adding a cell to the OPEN list as do the ordered searches. This yields a conceptually simpler algorithm, but one that produces a combinatorical explosion when applied to the problem of finding optimal routes on a gridded map. The uniform-cost search was allowed to run until the heap contained 500,000 nodes, but it still had not found a solution.

EVALUATION METHODOLOGY

The Combat Maneuver Model (CMM) computes the total time required for a selected group of vehicles to traverse a series of terrain units. The vehicles must travel in one of four basic formations. These four formations are a column, a bounding overwatch, combat lines, and parallel columns. The minimum and maximum following distances for vehicles within a column formation in addition to a maximum allowed speed are input by the user, thus allowing modeling of both Open or Closed column formations. In the bounding overwatch, the first vehicle travels out to a user designated distance and then waits for the second vehicle to reach it before proceeding. All other vehicles in the bounding overwatch are modeled as if they are in a column. The combat line consists of single vehicles traveling along parallel paths while staying within a user designated distance in relationship to each other. The parallel columns are modeled as a combination of the combat line (for the lead vehicle in each column) and as a column (for all but the lead vehicle in each column.

Each vehicle's progress is monitored at a user specified time interval. A small interval (5 seconds or less) is preferred, since it should yield more accurate modeling of vehicle interaction within the column. Each time interval may be evaluated twice. First, each vehicle will traverse the terrain, obeying terrain speed limits, until the time interval is over. At the completion of each time interval, the position of each vehicle is checked to determine that the formation's unity is maintained. If distances between vehicles are too large or too small, certain vehicles are required to proceed at a slower pace over the time frame to maintain proper vehicle spacing within the formation.

ACKNOWLEDGMENT

The tests described and the resulting data presented herein, unless otherwise noted, were obtained from research conducted under the MILITARY RESEARCH DEVELOPMENT TEST AND EVALUATION PROGRAM of the United States Army Corps of Engineers by the U.S. Army Engineer Waterways Experiment Station. Permission was granted by the Chief of Engineers to publish this information.

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THE ENGINEER MODEL IMPROVEMENT PROGRAM PLAN

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I. INTRODUCTION

1. Purpose. The Engineer Model Improvement Program (EMIP) is a comprehensive effort that is designed to ensure that engineers are properly represented in the Army's land combat models. This paper outlines a plan that was developed by the US Army Engineer Studies Center (ESC) to initiate and manage that program.[1] This plan was developed in support of the US Army Engineer School (USAES) and in conjunction not only with the USAES, but also the broader "engineer community" and the affected Army "analytic community."

2. Scope. The EMIP plan:

a. Identifies the problems associated with engineer representation in current Army models.

b. Identifies and prioritizes the work required to correct these problems.

c. Schedules this work over a 4-year period, with emphasis on completing the critical tasks within 2 years.

d. Estimates the analytic effort required, and displays annual funding and manpower requirements.

e. Addresses the question of who is available to do the work.

3. Background.

a. **The Army Model Improvement Program (AMIP).** In 1979, the Review of Army Analysis found several deficiencies in the Army's computerized combat models: poor documentation, poor response to study needs, inconsistent results, differing data assumptions, lack of interface structure, and limited (or no) functional area representation.[2] As a result, a directive was implemented for an Army Model Improvement Program (AMIP) in April 1980. Tasks and responsibilities within the AMIP are described in Army Regulation (AR) 5-11.[3] The goals of the AMIP were to improve the Army's analytical capability, improve model consistency and responsiveness, establish data base design and management, apply emerging computer technology, develop training applications, and stem model proliferation. These goals were to be accomplished by developing, documenting, and implementing a hierarchical family of computerized combat models which are supported by functional area models (as shown in **Figure 1**).

(1) Headquarters, Department of the Army delegated primary responsibility for overseeing AMIP activities to the Commanding General, US Army Training and Doctrine Command (CG, TRADOC). An AMIP Management Office (AMMO) was established to assist in coordinating and directing AMIP activities. AMIP advice and guidance were to be provided by the Army Models Committee (AMC), which was formed in 1981 as a continuing committee. The chairperson of the AMC is the Deputy Under Secretary of the Army for Operations Research.[4]

(2) The USAES was designated by the CG, TRADOC, to be the engineer proponent for AMIP modeling efforts. As such, the school has had the overall responsibility of ensuring that the engineer functional area is properly represented in the AMIP models.

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[1]*The Engineer Model Improvement Program Plan (Engineer Studies Center, August 1988).*
[2]*Review of Army Analysis, Department of the Army (DA) Special Study Group, April 1979.*
[3]*Army Model Improvement Program, AR 5-11 (DA, 15 August 1983).*
[4]*Management responsibilities may change as a result of a current AMMO reorganization. Details will be provided in the revised AR 5-11 scheduled for early fall 1989.*

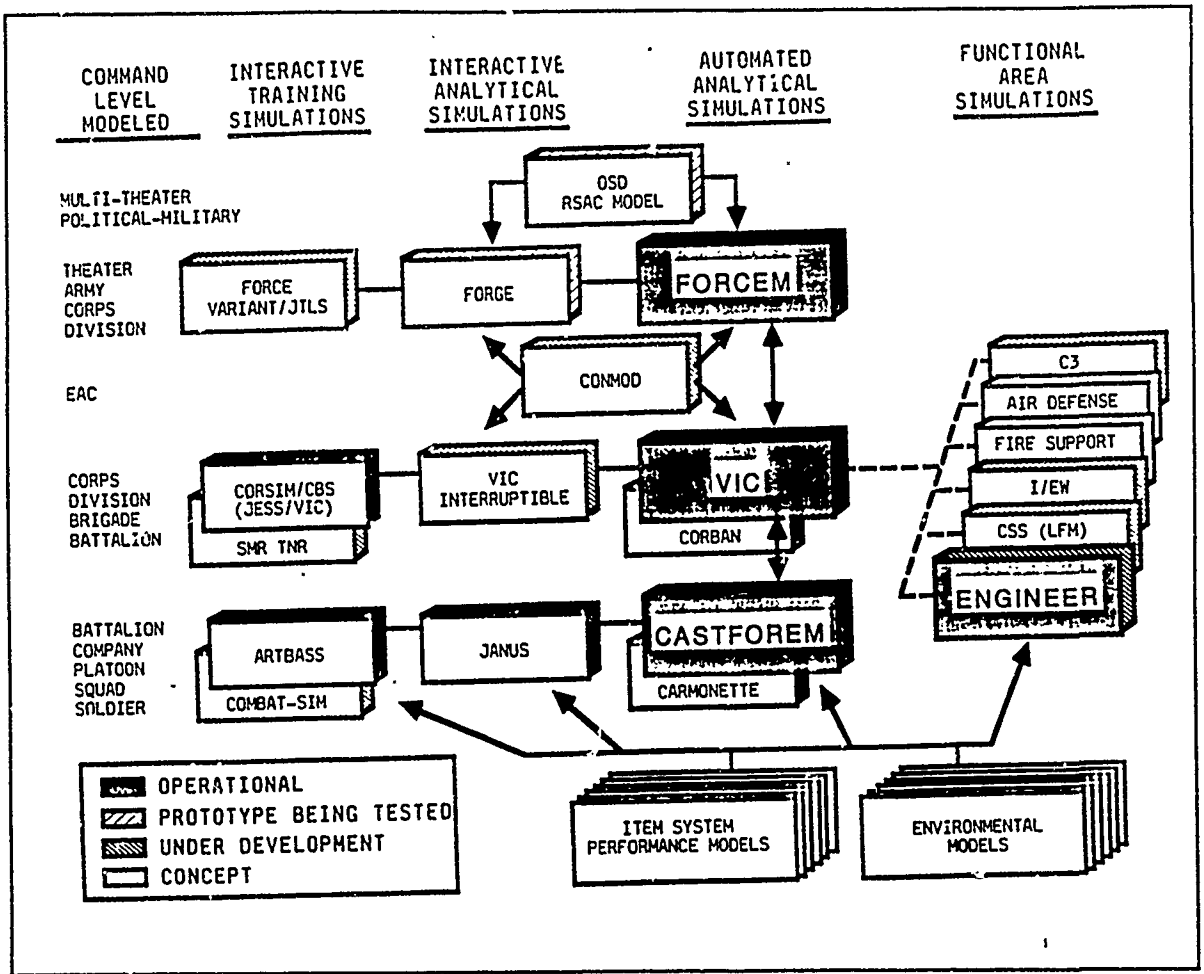

Figure 1 AMIP HIERARCHY

b. **US Army Corps of Engineers' (USACE) involvement in AMIP.** USACE has been involved primarily in a support role. As such, it has provided model development resources to USAES and, in turn, the Army modeling community. Both the Construction Engineering Research Laboratory (CERL) and the Waterways Experiment Station (WES) have had engineer modeling programs, some of which pre-date the 1980 establishment of AMIP. Thus, combat engineer modeling has been a high priority effort in USACE, especially in their research and development programs.

c. **ESC Involvement in AMIP.** ESC's involvement with AMIP began in the fall of 1985. During October and November of that year, a series of messages was sent by USAES, USACE, and the TRADOC Analysis Command (TRAC), all in reference to a possible increase in the engineer staff at HQ TRAC. The primary objective was to help TRAC model the value of engineers as members of the combined arms team. As a result, USACE proposed to assign an engineer officer to ESC, with duty station at HQ TRAC. The mission, functions, and operating procedures associated with this new position were formally agreed to of Understanding between the Commandant, USAES and the deputy commanding generals of both TRAC and USACE. In August 1986, a former engineer battalion commander was selected to fill this newly created position.

(1) USACE went beyond simply stationing one ESC officer at Fort Leavenworth. The CG, USACE, also assigned ESC a combat engineer modeling mission. ESC's experience with worldwide engineer assessments, evaluation of engineer unit designs, and evaluations of engineer

doctrine placed it in a unique position to be a focal point for USACE modeling support. To this end, on 3 December of 1986 the CG, USACE, also assigned to ESC the following missions:

(a) Monitor and evaluate the representation of engineers within the hierarchy of Army models and provide, in coordination with USAES, recommendations to the AMC.

(b) Provide primary USACE interface with the AMMO and other AMIP organizations on matters relating to engineer modeling.

(c) Serve as the USACE point of contact for the Army Staff on all matters pertaining to AMIP engineer modeling.

(d) Serve as USACE program manager for AMIP engineer model improvements provided by USACE laboratories.

(2) To clearly delineate ESC's relationship with the USAES, the CG, USACE, specifically highlighted the following:

> *The designation of ESC as the Center of Combat Engineer Modeling within USACE is intended to strengthen the engineer community's involvement in modeling. This designation does not circumvent the duties and responsibilities of the USAES as the Engineer Proponent with its prescribed responsibilities under TRADOC for modeling. ESC's AMIP work and modeling initiatives will be fully coordinated with, and concurred in, by the USAES.*[5]

d. **ESC's Involvement in the Engineer Model Improvement Program (EMIP).** From the beginning, ESC believed that the representation of engineer forces within the hierarchy of Army models could best and most consistently be achieved by a centralized program that represented the views of the senior engineer leadership. However, ESC also believed that a centralized program must be developed in coordination with the Army modeling community and be fully supported by the AMC. It is for these reasons that ESC has developed, staffed, and gained the engineer and Army analytic communities' approval of this EMIP plan.

4. Limits. ESC's combat engineer modeling mission is limited to those land combat models included within the hierarchy of Army models. Furthermore, this EMIP plan focuses only on improvements that are needed to the fully automated models, which include the Combined Arms and Support Task Force Evaluation Model (CASTFOREM), the Vector-in-Commander (VIC) model, and the Force Evaluation Model (FORCEM). However, this plan also addresses the development of an Engineer Functional Area Model (EFAM).

5. Method. ESC used the three-step approach shown in **Figure 2** to develop this plan:

a. **Step one.** ESC assessed the current level of engineer representation in the fully automated AMIP models. During its analyses, ESC focused attention on three related aspects of engineer modeling by asking the following questions of each model:

(1) Engineer task effectiveness. Does the structure of the model adequately represent the effects of engineer task execution?

(2) Engineer unit effectiveness. Does the model represent engineer task execution on the battlefield, and can the requirements for, or capabilities of, an engineer force be measured?

(3) Terrain representation. Does the model use the quality and quantity of digitized terrain data needed to adequately measure the influence of terrain on the outcome of the battle?

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[5] *Letter, US Army Corps of Engineers, dated December 3, 1986, subject: Engineer Studies Center's Role in Engineer Modeling.*

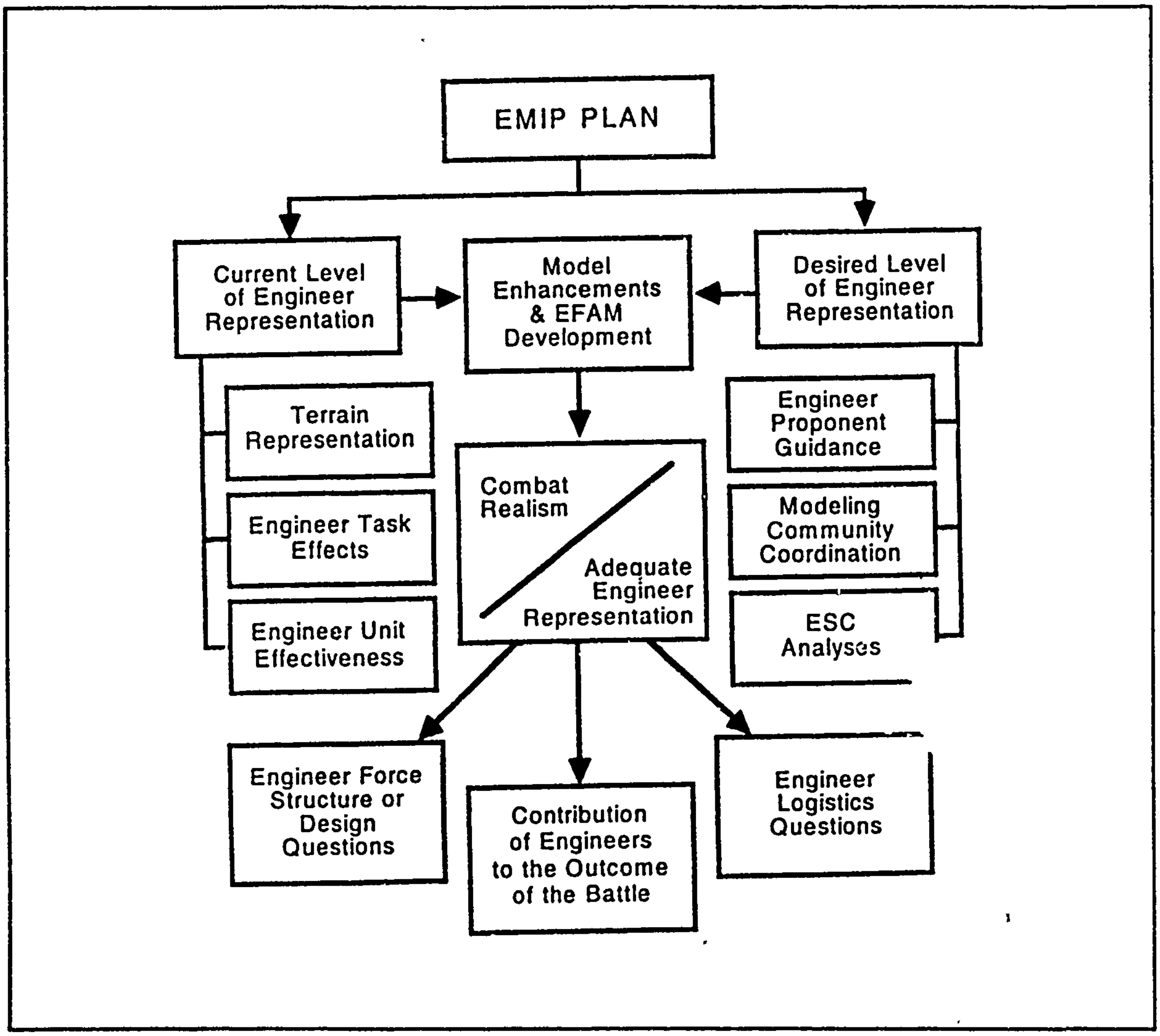

Figure 2 EMIP METHODOLOGY

b. **Step two.** ESC established the desired level of engineer representation in the AMIP models. The primary criteria used to develop this assessment included: an ESC analysis of engineer tasks, input from the Army modeling community, and USAES guidance.

c. **Step three.** Based on the discrepancies between the current and desired levels of engineer representation, ESC developed an aggressive model improvement plan that addresses: the necessary enhancements to CASTFOREM, VIC, and FORCEM; requirements for an EFAM development; and digitized terrain data base requirements to support all models.

II. ENGINEER FUNCTIONS AND ARMY MODELING

6. Introduction. As previously stated, the purpose of the EMIP is to ensure that engineers are properly represented in the Army's combat models. ESC has translated this purpose in a two-fold objective. First, the models should realistically represent the combined arms conflict. This objective cannot be accomplished without a realistic representation of the role that combat engineers play in the combined arms team. Second, the degree to which the engineer functions

are represented in any particular combined arms model should be commensurate with the model's intended use and level of resolution. With this in mind, ESC established guidelines for the types of engineer tasks that should be considered in high-, mid-, and low-resolution models, and used these guidelines to evaluate CASTFOREM, VIC, and FORCEM. In this section ESC summarizes that effort, generally describes the engineer's role in a combined arms environment, and explains how this role should be modeled.

7. Engineer Missions. Army Field Manual (FM) 100-5, Operations, gives the Army's basic warfare doctrine and describes how combat engineers contribute to the combined arms team. Engineer missions are developed in more detail in: FM 5-100, Engineer Combat Operations; FM 5-101, Mobility; FM 5-102,Countermobility; FM 5-103, Survivability; and FM 5-104, General Engineering. These FMs define the following combat engineer mission areas:

a. **Mobility.** US forces conduct mobility tasks to obtain and maintain the freedom of both tactical maneuver and operational movement. Mobility missions include: breaching obstacles, conducting river crossing operations, and preparing and maintaining pioneer trails.

b. **Countermobility.** Countermobility efforts have an ultimate goal of delaying, stopping, or channelizing the enemy. Engineers perform countermobility tasks by installing linear obstacles (e.g., minefields, antitank ditches) or point obstacles (e.g., road craters, bridge demolitions)

c. **Survivability.** The concept of survivability includes all aspects of protecting personnel, weapons, and supplies while simultaneously deceiving the enemy. Survivability tactics include: constructing fighting and protective positions for both individuals and equipment; and using concealment, deception, and camouflage.

d. **Sustainment engineering.** Sustainment engineering primarily supports the rear areas which, in turn, support the forward-deployed force. It includes functions such as maintaining main supply routes, repairing airfield damage, and maintaining rear area facilities.

e. **Topographic engineering.** Topographic engineering assists field commanders in using the terrain more effectively. Topographic functional areas include terrain analysis, map production (cartography, map reproduction, and topographic survey), and map distribution.

8. Engineer Employment. Engineer troop units provide support throughout the theater of operations. Combat engineer units are assigned missions in the forward combat zone (FCZ) in the division and corps areas. Engineer combat heavy battalions are assigned missions in both the FCZ and the communications zone (COMMZ). Separate engineer companies and teams are assigned where needed.

a. **Support in the division area.** Each US Army division has an organic divisional engineer battalion which operates as part of its combined arms team. Each engineer battalion's companies are normally associated with a particular divisional brigade or task force. These engineer companies are normally placed in direct support or under operational control (OPCON) of the supported force. Engineer battalions which are organic to airborne, air assault, and light infantry divisions have fewer resources than the engineer battalions in the other divisions. They have fewer personnel, less earth moving equipment, and no bridging capability. Separate brigades and armored cavalry regiments also have organic engineer companies. An engineer terrain team of the theater topographic engineer battalion normally supports each division.

b. **Support in the corps area.** The composition of engineer units in a corps area depends primarily on the mission, threat, and terrain in the specific area of operations. It also depends on the availability of host nation assets and the size of the supported maneuver force. In general, for a five-division corps in the European theater, the doctrinal engineer force might include: a brigade headquarters; two or more group headquarters; 12 corps battalions; three heavy battalions; six float bridge companies; four medium girder bridge companies; six combat support equipment companies; two dumptruck companies; a cartographic company; five divisional terrain teams; a corps terrain team; a topographic survey platoon; and cellular teams for real property maintenance activities, as required.

c. **Support in the COMMZ.** The requirements for engineer support in the COMMZ depend largely on the character, magnitude, and phasing of base development operations. Base development includes the initial beddown of logistics units; the repair and renovation of Lines of Communication (LOCs) and facilities needed to support the receipt, storage and distribution of war materiel; and the logistics base expansion required to establish a mature theater. Because the size and make-up of the engineer COMMZ is so theater and operation plan (OPLAN) dependent, it is unproductive to provide a sample force sizing for the COMMZ. However, for a major theater, the engineer force would doctrinally contain an engineer command headquarters and several brigade headquarters (each with two or more group headquarters). Depending on the mission assigned, the group headquarters would command and control a blend of combat heavy battalions and construction support, dump truck, pipeline, port construction, and bridge companies. The engineer command and brigades would also control the numerous topographic units, as well as the facility-oriented companies and teams assigned to the theater.

d. **Support to other services and agencies.** Army engineers may also be directed to support other services and agencies in the theater of operations. Currently, Army engineers support the US Air Force (USAF) by accomplishing follow-on airfield war damage repair and restoration to damaged pavements and facilities, as well as all new construction requirements. Army engineers also assist with emergency war damage repair and beddown requirements that exceed Air Force civil engineering capabilities. The responsibility to support the Air Force is a major mission which places severe demands on several Army engineer units (combat battalion heavy, construction support equipment companies, and utility detachments) in a theater of operations.

9. Engineer Tasks. The above discussion indicates the diversity of tasks that engineers are expected to perform on the battlefield. **Figure 3** groups these tasks into 16 broad task categories based on the interaction between engineer functions and other combat functions. ESC used these broad task categories as a foundation from which to develop more specific recommendations about the modifications which are needed to better represent engineer play in specific models. ESC observed that:

a. **There are certain engineer task categories in Figure 3 that are outside the scope of high-resolution models (i.e. CASTFOREM).** For example, the short engagement times and the small battlefield size that are represented in high-resolution models make it impractical to represent such tasks as rear area facility damage repair and improving river crossing sites for follow-on forces.

b. **Most engineer task categories can be represented in mid-resolution models (i.e., VIC).** Since current mid-resolution models include the corps service areas, they come closest to covering all of the engineer task categories identified in Figure 3. Mid-resolution models also have the architectural structure to accommodate the inclusion of most engineer tasks in substantial detail.

c. **Some engineer tasks cannot be explicitly represented by low-resolution models (i.e., FORCEM).** The design of current low-resolution models is such that even the general list of 16 task categories cannot be explicitly represented at this level of aggregation. On the other hand, low-resolution models can address rear area operations that cannot be represented in models of other levels of resolution.

10. Engineer Modeling and CASTFOREM. CASTFOREM is a high-resolution, two-sided, stochastic simulation of a small combined arms conflict lasting, at most, 1-1/2 to 2 hours. It enjoys general acceptance throughout the modeling community. The model simulates a fire-fight between a defender of battalion-size (or smaller) unit against an attacker of regimental-size (or smaller). A typical CASTFOREM battle area is represented by 20 x 20 kilometers of terrain, graduated into 100 meter grid cells.

1. Install linear obstacles(minefields, tank ditches...)

2. Install point obstacles(road craters, bridge demolition...)

3. Prepare fighting positions for direct fire systems(tanks, TOWS...)

4. Prepare positions for indirect fire & other systems(artillery, ADA, CP,...)

5. Breach obstaclesin the assault (breach minefields, span short gaps...)

6. Improve assault breachesfor follow-on forces (clear minefields, widen lanes...)

7. Conduct river crossingoperation in the assault (bank clearing, rafting, assault bridging...)

8. Improve river crossingsite for follow-on forces (fixed bridging, float bridging...)

9. Maintain main supply routes (fill craters, build up worn shoulders...)

10. Pioneer trail preparation & maintenance(route clearing, soil stabilization...)

11. Forward airlanding facility preparation & maintenance(air strip clearing, soil stabilization...)

12. Site preparation & maintenancefor combat support & combat service support units (access road,site clearing...)

13. Rear area facility rehabilitation & maintenance(building conversion, damagerepair...)

14. Airfield damagerepair (crater repair, rubble clearing...)

15. Port & waterfront facilities construction & repair (pier repair, storagefacility rehabilitation...)

16. Other (engineer raids, nuclear rubble removal...)

Figure 3 ENGINEER TASK CATEGORIES

a. **Background.** In 1981, TRADOC Analysis Command, White Sands Missile Range (TRAC-WSMR) (then the TRADOC Systems and Analysis Activity), developed CASTFOREM as the battalion-level AMIP model. As originally conceived, this model is battalion task force level in scope and plays individual vehicles and weapon systems. Its capacity to handle complex scenario situations and detailed input data has made it an excellent replacement for CARMONETTE, the predecessor high-resolution model.

b. **Engineer modeling considerations.** CASTFOREM was designed to represent the detailed operations of the combined arms and support task force. Its primary purpose is to determine the effectiveness of units and individual systems. As such, only the "vital"[6] engineer tasks should be considered for representation in CASTFOREM. These vital tasks include: preparing fighting positions (direct-fire positions); installing linear obstacles; breaching obstacles in

[6]In its engineer assessments, the Engineer Studies Center has found it useful to collect ranked tasks into four priority groups -- vital tasks, critical tasks, essential tasks, and necessary tasks.

the assault; installing point obstacles; preparing fighting positions (indirect-fire and other systems); and conducting river crossing operations in the assault. Unfortunately, CASTFOREM has limited ability to explicitly play the execution of these tasks. This is due to the short duration of simulated battle (only 2 hours), the small size of the terrain box (only 400 square kilometers), and the high resolution of the maneuver units (usually company size). Nevertheless, the effects of these tasks are critical to CASTFOREM realism.

11. Engineer Modeling and VIC. VIC is a two-sided, deterministic computer simulation of combat in a combined arms environment. The model is designed to provide a balanced representation of the major force elements of a US Army corps in a tactical campaign. The modular program structure represents friendly air and land forces and a commensurate enemy force in a mid-intensity battle. The model is event-stepped for maneuver elements and time-stepped for calculating support effects. Maneuver units in VIC initially move along scripted paths. Decision tables exercise command and control in the automated simulation. The model has a pre-processor for constructing input data files and comprehensive post-processors for displaying model results. VIC users generally represent terrain in 4 x 4 kilometer grid squares. Three terrain data classes (vegetation, relief, and linear obstacles and features) normally affect the modeled maneuver units' movement and visibility. VIC has been used by TRAC-WSMR and TRADOC Analysis Command, Fort Leavenworth (TRAC-FLVN) on six major studies and typically simulates three to six days of combat.

a. **Background.** In 1982, TRADOC established a requirement for a corps-level model in which AirLand Battle Doctrine could be represented and studied. TRAC-WSMR decided to take advantage of, and improve upon, the best features of existing models rather than to develop a completely new model. Specifically, VIC was based on: the Vector-2 model's representation of ground combat (developed by Vector Research, Incorporated), and the USAF's Commander Model's representation of the air war (which evolved from the Talon Model). In 1985, a review committee, which was appointed by the AMC, recommended VIC as the Army's corps/division-level model. In 1986, VIC was adopted into the Army's hierarchy of simulation models under AMIP, replacing the Corps/Division Evaluation Model (CORDIVEM) simulation. VIC was placed under configuration management by HQ TRAC in April 1987.

b. **Engineer modeling considerations.** According to AR 5-11, VIC is to be used for force design and development of concepts, doctrine, and tactics for corps, divisions, and brigades. It will also be used to determine resource requirements for sustained operations and to study materiel systems that are organic to, or have an influence on, the capabilities of corps, divisions, or brigades. Because it is the Army's mid-resolution corps/division simulation model, VIC should, as a minimum, represent the engineer tasks that are performed forward of the corps rear boundary. But, unlike CASTFOREM, which focuses on the effectiveness of individual weapon systems, VIC represents the interactions of the various combat, combat support (CS), and combat service support (CSS) functional areas. Therefore, the execution of engineer tasks should be modeled, as well as the effects of those engineer tasks.

12. Engineer Modeling and the Force Evaluation Model (FORCEM). FORCEM is a two-sided, time-stepped, deterministic theater-level wargame. It plays both ground and air combat. Unlike most other theater models, FORCEM has a multi-tiered decision making framework and includes the role of CSS forces at echelons above corps. FORCEM has three major functional areas: situation development, command and control, and an activity portion consisting of combat and support elements. Situation development builds a perception base by simulating the gathering and processing of intelligence information, and the transmission of that information among headquarters. The situation data is used by command and control for decision making at corps, army, and theater headquarters. The decision making process controls unit and resource dispositions using hard-wired decision rules controlled by various input parameters. Combat occurs at several levels: at the maneuver unit level; at the air war level; and at the deep strike artillery and

surface-to-surface missile level. Medical, supply, transportation, maintenance, vehicle recovery, personnel, and engineer functions comprise support activities currently modeled in FORCEM.

a. **Background.** In July of 1981, AR 5-11 tasked the US Army Concepts Analysis Agency (CAA) with the responsibility for the theater level component of the AMIP hierarchy -- the Force Evaluation Model. FORCEM development began at CAA in 1982, and the first working version was completed in 1985. FORCEM has been used on three major CAA studies: US Army Operational Readiness Analysis-1985 (OMNIBUS-85); OMNIBUS-86; and the Combat-Support Ratio Study. Although FORCEM was used in the first study for demonstration purposes, the latter two efforts were full-fledged study applications. FORCEM is currently being employed on the OMNIBUS-89 study.

b. **Engineer modeling considerations.** CAA designed FORCEM to become the Army's principal theater-level wargame. While it has been used successfully on several studies, FORCEM has not reached its full potential as outlined in AR 5-11. Originally, FORCEM was to support both capability and requirements analyses, relying on the division/corps results from CORDIVEM. To date, FORCEM has evolved into a capabilities model that relies on division-level combat samples from Combat Sample Generator (COSAGE), and on Force Analysis of Theater Administrative and Logistics Support (FASTALS) to round out those portions of the force which are not represented in FORCEM (e.g., engineers). CAA is constantly improving FORCEM so that it will eventually attain its desired functional capacity. Once these improvements are made, FORCEM could then be used to support both program analyses and force design. The "ideal" engineer representation in FORCEM would simulate all the tasks in Figure 3. Such an "ideal" version is, of course, realistically unattainable because of the way engineer functions are represented. Also, the level of resolution of engineer functions must be compatible with the other functional components in the model. The challenge then is to adapt engineer representational needs with FORCEM's design, components, and computational limits.

III. CONCLUSIONS

13. The Quality of Engineer Modeling Has Not Been Good. Historically, there have been serious deficiencies in the modeling of engineer functions in available force-on-force simulations. From the early 60's to the late 70's, engineer representation in the Army's land combat simulations was minimal, at best. The lack of adequate engineer representation in the Army's analytical models received little, if any, formal attention from the Army's analytic community. This general state of neglect was probably rooted in the ad hoc process that was commonly used at the time to develop models. Engineer-related studies were never high enough in the queue to receive anything but casual interest from the modeling community. Since these combat models were being used in almost all Army studies of combined arms' systems, engineers were at a severe disadvantage. Because of inadequate engineer representation in these models, the engineer community could not demonstrate to the Army the engineers' contribution to combat force effectiveness. Conversely, the engineers were also not able to analyze engineer material and equipment requirements within the context of a combined arms simulation. This inadequacy of combat engineer modeling was recognized by sources outside the engineer community in a 27 February 1980 memorandum in which the Army Chief of Staff urged the Chief of Engineers "...to relook the manner in which engineers state and support combat engineer systems."

14. The Situation Has Improved. Beginning in 1979, the Army moved toward the development of a hierarchy of combat and support models under AMIP. This was a positive step away from the ad hoc model developments that had previously thwarted engineer representation. About the same time, the USAES established an Engineer Modeling Program. The primary goal of the Engineer Modeling Program was to develop an engineer module for AMIP's corps level model (initially called the Corps Battle Game and later called CORDIVEM). Under the auspices of AMIP

and the Engineer Modeling Program, engineer modules were developed for CASTFOREM, CORDIVEM, and FORCEM.

15. Problems Still Exist. Despite recent improvements in the representation of engineers in the AMIP models, problems do still exist. They include:

a. **The Army land combat models do not adequately demonstrate the contribution of combat engineers to the combined arms battle.** ESC believes that problems still exist with the current engineer representation in the following AMIP models:

(1) CASTFOREM. This model currently simulates engineer activities very modestly. Those engineer-related activities now modeled are modeled implicitly, instead of explicitly. Only protective positions are represented in enough detail to accurately portray their effects on the overall battle. Counter-obstacle activities are simulated simplistically; each force which encounters an obstacle is assessed both a predetermined time delay and a predetermined number of casualties. The time delay represents an average time necessary to bring forward an unspecified breaching system and to breach the obstacle. Breaching assets are assumed to be available at all times and are not attrited. This implicit modeling of some engineer activities, coupled with the lack of representation of other activities, weakens the reliability of CASTFOREM as a conflict simulation.

(2) VIC. In VIC, only engineer units at the lowest level can perform work: minefield teams (emplace only); linear obstacle teams (emplace only); bridging teams; and survivability teams (defensive position construction). While VIC does account for unit-allocated equipment and has the capability to attrit specific classes of equipment, the availability and capability of that equipment does not affect the rate at which engineer units accomplish their tasks.

(3) FORCEM. To find engineer play, one must look to models that support FORCEM: COSAGE produces the samples used for combat results calculations; and FASTALS determines engineer unit resource requirements for COMMZ tasks through the force round-out process. After looking at engineer play or treatment across all three models, ESC found the following:

(a) COSAGE considers only one engineer related activity --the breaching of pre-emplaced minefields. The method used to extrapolate results from combat samples, as well as the samples themselves, appears to ignore the role of engineer forces. Thus the important role of divisional and corps engineers on the battlefield is ignored.

(b) Although FASTALS does consider some engineer tasks, it does not include several "vital" tasks that have important resource and force effectiveness implications. Task estimates appear to use workload parameters that are both overly general and subjective. More importantly, since it is a requirements model, FASTALS cannot indicate what effect engineers have on the conduct of the war.

(c) FORCEM also fails to consider such tasks as US Army engineer assistance to USAF engineers when airbase damage or beddown requirements exceed USAF capability. Even if VIC replaces COSAGE as the combat sample generator, the engineer work which occurs in the corps rear (the gap between COMMZ and FCZ) is likely to remain unaddressed.

b. **Engineer-sponsored studies are typically not high on the TRADOC list of priority studies.** Even though historically the combat engineer has been an indispensable member of the combined arms team, studies to support the modernization of the engineer force cannot successfully compete for scarce TRAC modeling resources. The consequences of this low priority for engineer studies is twofold. First, since most of the enhancements to production models (i.e. CASTFOREM, VIC, and FORCEM) are study-driven, engineer representation in these models does not evolve as rapidly as does the representation of other higher priority functional areas. (The top priority at TRAC is study support -- not model research and development.) Second, the USAES must look elsewhere for modeling support. The USAES has access to several non-AMIP models, but none that are both adequate to address engineer-specific questions and provide credible results in the eyes of the Army's analytical community. The engineer study program suffers on both counts.

c. **The availability of digital terrain data (DTD) is not adequate to support the Army's analytic community.** Identification and production of DTD to support the Army's analytic community has been inadequate. Most DTD coverage for the Army's OPLANs is for locations supporting TRADOC-approved scenarios in the Federal Republic of Germany (FRG). As a result, CAA cannot conduct simulations which adequately represent terrain (and therefore engineer functions) in their other theater-level studies. DTD inadequacies also preclude agencies such as ESC and Army Materiel Systems Analysis Agency (AMSAA) from adequately representing terrain in their VIC or CASTFOREM simulations of combat in world areas other than the FRG.

IV. RECOMMENDATIONS

16. <u>Only a Few Changes Are Needed in CASTFOREM</u>. For engineer unit and force structure studies, CASTFOREM's applicability is limited. It cannot be expected to realistically model the engineer's flexible and responsive support structure. It is, however, an invaluable tool for evaluating the effects of specific engineer tasks (e.g., emplacing obstacles) or the operational effectiveness of individual engineer systems. With the recent development of a new minefield breaching module, USAES and TRAC-WSMR have made substantial progress toward adequately representing engineers in CASTFOREM. Only a few additional changes are recommended at this time to improve the realism of CASTFOREM's combined arms representation. Those improvements are discussed in detail in the EMIP Plan.

17. <u>VIC Requires an Expansion in the Number of Engineer Tasks and Effects That Are Currently Represented</u>. VIC was designed to represent the interactions of the various combat, CS, and CSS functional areas. As an analytical tool, its purpose is to support design and structure tradeoff analyses of Army organizations such as brigade, division and corps. (VIC can also support studies of certain item systems organic to major organizations.) It is for these reasons that VIC must provide a reasonable and balanced representation of each functional area, and accurately portray the contribution of each functional area to the combined arms conflict. Currently, VIC represents a few engineer tasks and effects well. However, many tasks and effects are represented poorly or not at all. To maintain a reasonable and balanced representation in VIC, engineer units should continue to be modeled explicitly. However, the representation of engineer unit capability under a more flexible modeling arrangement could improve the realism of the current tasks played in the model and permit the inclusion of additional engineer tasks. The EMIP Plan identifies 37 improvements that ESC recommends be made to the engineer representation in VIC.

18. <u>Adequate Engineer Representation in FORCEM Will Require a New Engineer Module, in Addition to Changes in Existing FORCEM Elements</u>. FORCEM was designed to become the Army's principal theater-level wargame. Looking to that time, FORCEM will have to be improved if it is to fairly represent engineer activities in the theater well enough to evaluate capabilities and calculate requirements. Moreover, the improvements are interrelated; accomplishing one without making progress in others will gain nothing. Unless terrain and installations are satisfactorily represented, the effects they have on various modeled units and processes cannot be calculated. Nor can engineer tasks have any reasonable basis without adequately representing the object on which they work. The EMIP Plan identifies the specific improvements ESC recommends for FORCEM.

19. <u>The Engineer Community Needs a Functional Area Model</u>. Each proposal for improving the Army's equipment, organization, or training must be analyzed in detail to demonstrate the cost and operational effectiveness of the proposed change. Those organizations or systems with the greatest perceived pay-off are normally chosen for acquisition. Combat engineer systems, lacking the support of robust analytical techniques, often do not make the initial cut. There are several reasons for this. First, the Army land combat models do not adequately demonstrate the contribution of engineer systems to the combined arms battle, much less have the breadth and

depth to address specific engineer issues. Second, even if they did, engineer-sponsored studies are typically not high on the TRADOC list of priority studies. Therefore, they are often performed without modeling support from TRAC, using models that do not have the credibility that AMIP models enjoy. A developmental program should be undertaken with the ultimate goal of providing USAES with an appropriate, analytically acceptable, and Army approved corps/division-level model. The EMIP Plan presents the requirements specifications for an EFAM. Generally, the model should be stand-alone, but logically linked to VIC. It must be capable of addressing the following types of analyses:

a. Engineer force structure or design questions.
b. Engineer logistics questions.
c. Contribution of engineers to the combined arms conflict.

20. The Army Needs More Extensive Area Coverage For DTD. ETL included the needs of the Army analysis community in their 1984 study, Army Digital Topographic Data Requirements. These requirements were validated by ODCSINT and were formally presented to the Defense Mapping Agency (DMA) in October 1984. However, DMA does not plan to begin producing data to meet these requirements until some time after 1992. The Army must, therefore, establish its most critical DTD needs (those that cannot wait for the new DMA system) and develop a cost effective method of producing this urgently needed data. To avoid needless duplication of effort, the Engineer Topographic Laboratories (ETL) must establish standards and specifications for the Army's interim terrain product needs and require that all new production efforts follow these standards. The EMIP Plan discusses the current DTD deficiencies in detail, proposes an organization that should be charged with correcting these deficiencies, and estimates the professional staff years of effort (and dollar cost) that must be committed to solve the problem.

21. Off-line Analysis Addressing Engineer Task Effectiveness Will Be Required to Support Model Development. Before an engineer task can be successfully integrated into an AMIP model (including EFAM), supporting data will have to be developed. ESC recommends that each engineer task be researched and analyzed using: historical data; results of field tests/exercises; and surveys of opinions from subject matter experts. Deficiencies in the available data necessary to support the modeling of engineer task effects should be identified and appropriate remedial actions taken.

MINEFIELD ATTRITION, DELAY, AND MOBILITY MODEL

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ABSTRACT

The Minefield Attrition, Delay, and Mobility Model (MADMM) is a stochastically-based, high-resolution mine/countermine model which can be used for asset allocation studies, algorithm validation, and to generate input data for lower resolution models such as Vector-in-Commander (VIC). MADMM simulates up to a battalion-sized force attacking through mine obstacles on one or more avenues of approach. MADMM can model several types of minefields with or without covering fire. It is also capable of modeling a variety of breaching assets, weapons systems, and vehicle types.

BACKGROUND

MADMM was originally developed to qualitatively validate the minefield attrition and delay algorithms in the medium-resolution combat simulation model VIC under the Engineer Model Improvement Program (EMIP). However, it was designed to be extremely flexible and general in nature so it could also be used for minefield and breaching-asset effectiveness studies, among other things.

In lieu of writing a new mine warfare simulation program, the High Resolution Minefield Model (HiRMM) model (Reference 1) was chosen as the starting point for MADMM. Other high-resolution minefield models were considered for the VIC work; however, they were excluded because of difficulty in use, lack of resolution, and improper or insufficient representation of the aspects of mine warfare of interest.

HiRMM was developed at the U.S. Naval Postgraduate School for studying the optimum mix of track-width mine plows and track-width mine rollers for the M1 tank. Because it played the individual vehicles in a battalion-sized force, it was ideally suited to VIC's level of aggregation, which generally consists of battalion-sized fighting units and company-sized support units.

AN OVERVIEW OF MADMM

MADMM is a stochastically-based, high-resolution model that simulates a battalion-sized force attacking through mine obstacles on one or more avenues of approach. The attacker's objective is defended by a company-sized force employing direct-fire weapons. The user has control over such aspects as the size and weapons mix of both the attacking and defending forces, the number of avenues of approach, the mobility along those avenues, the number of minefields, the minefield depths and densities, and the mine types employed.

MADMM is written in FORTRAN for a PC-DOS Based personal computer. Simulation times typically take between 1 to 2 hours for 100 repetitions (the minimum needed for convergence on a solution). A graphics preprocessor written in the C language was developed to generate the avenues of approach and the multiple formations used by the model and to store that data in files for future use. The preprocessor also guides the user through the process of setting up the PH and PK tables for determining the effectiveness of each weapon system against each vehicle type on the opposing side. Once developed, these too can be stored on file and recalled for future use.

The output from the model consists of a history of the battle showing the times and locations of each vehicle's hit and kill, a summary of vehicle and breaching asset kills due to direct fire and mines, and a summary of the battle presented in the form of measures of effectiveness such as average length of battle, percentage of casualties due to mines, and rate of battle losses.

THE PLAYING FIELD

At the heart of MADMM is a user-defined network of nodes and arcs which represent the playing field. The network determines the path and speed of the vehicles as they advance on the objective as well as the locations of the minefields and the defending force. Units move as rigid, user-defined vehicle formations that key off of a "ghost vehicle" which determines the position and speed of the unit at any point in time. Unit movement along the network's arcs is time-stepped using a 30-second interval. Figure 1 shows a sample network overlaid onto a simple terrain. As shown in this figure, multiple units can traverse the same path.

Each arc in the network may contain a minefield with the only restriction being that the arc must be longer than the depth of the minefield. Minefield depth is determined by a random-number draw between user-specified minimum and maximum depth limits. The leading edge of the minefield is assumed to coincide with the tail node of the arc and the orientation of the minefield is assumed to be perpendicular to the line of advance. At the present time, the minefields are represented as a uniform distribution of mines randomly dispersed within a rectangular area; future versions will include a Gaussian distribution of mines randomly dispersed over an elliptical area to simulate artillery-delivered mines. Minefields can contain multiple mine types with each mine type having its own density.

For each combination of mine and breaching asset type, there is a probability that the mine will be cleared, that it will detonate given that it was cleared, and that the breaching asset survived assuming that the mine detonation. For each combination of mine and vehicle type, there is a probability of a vehicle kill assuming that the mine was not cleared. This

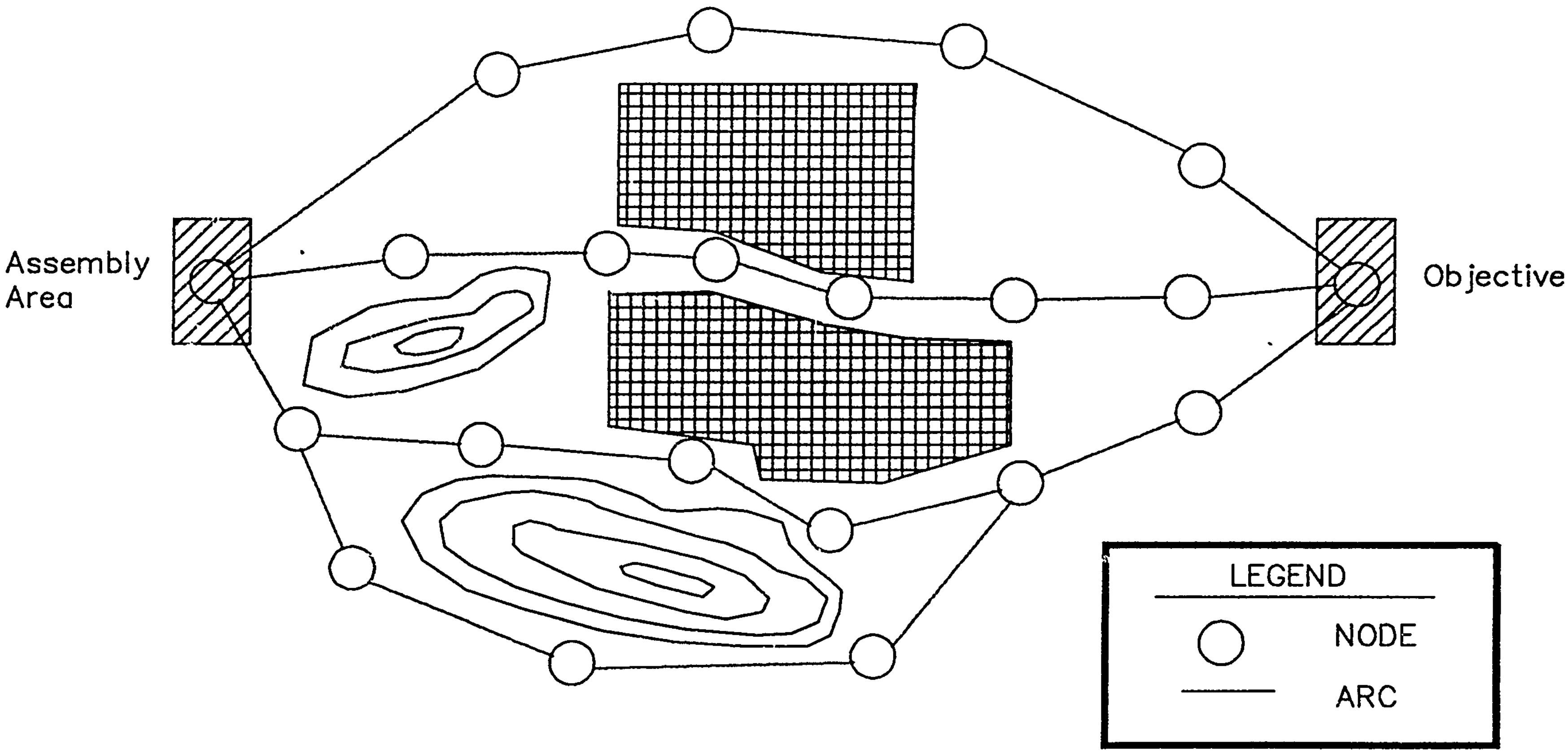

Figure 1. The MADMM playing field.

probability extends to the breaching asset carriers, which can be killed if they do not successfully clear the mine.

VEHICLES AND BREACHING

Vehicles begin the simulation in a user-defined advancing formation, an example of which is shown in Figure 2. If and when a minefield is detected (either visually or by detonation), a decision is made as to the minefield tactic to adopt. The choice of a tactic depends upon the unit's assets and knowledge of the minefield. If the knowledge is gained prior to entering the minefield (i.e., through visual detection), the unit conducts a hasty breach if it has breaching assets or a bypass if it does not. If knowledge of the minefield is gained after entry (i.e., through mine detonation), three possible tactics are available. If the unit possesses breaching equipment, it begins the breaching operation from the point where the mine detonation took place since it is assumed that up to that point the minefield has been successfully breached. If the unit does not have any breaching equipment, and assuming perfect knowledge of the minefield boundaries, the decision to bull through or bypass is based on the distance into the minefield that the detonation took place. The applicable distance can be specified by the user to reflect the doctrinal tactics of the advancing side.

If a breaching tactic is adopted, the transition into a breaching formation to include overwatch positions set up on the near side of the minefield. Utilizing a user-defined sequence and vehicle spacing, vehicles are moved through the minefield singly or in tandem to post-breach positions on the far side of the minefield. A similar methodology, with different formations, is used when a bull-through tactic is chosen. Figure 2 shows sample breach and post-breach vehicle formations for a hasty breach. Figure 3 shows a sample breaching sequence involving multiple breach lanes. During the entire time that the unit is in the minefield, vehicle movement is event-stepped from one mine detonation to the next. The entry and exit of each vehicle as it crosses the minefield are also treated as events. This is done in order to model the breaching process as precisely as possible.

If a bypass tactic is implemented, the vehicles remain in their advancing formation but move at a degraded speed to affect the delay in forward progress that would result from having to move parallel to the minefield in hopes of discovering a route around the obstacle. In this way, the unit is delayed in reaching its objective and subjected to enemy fire for a longer period of time without having to build additional arcs and nodes to describe a bypass route.

Once the vehicles have crossed the minefield, they continue their movement toward the objective in a detection formation. The detection formation is more cautious of minefields than the advancing formation and would usually place the mine rollers in the lead (if the unit has any left or had any to start with). The unit remains in the detection formation ntil the next minefield is encountered or the objective is reached.

The simulation is over when the defending position is over-run, the defending force drops below a threshold value specified by the user, or all of the aggressing units have assumed a defensive posture. The latter involves a

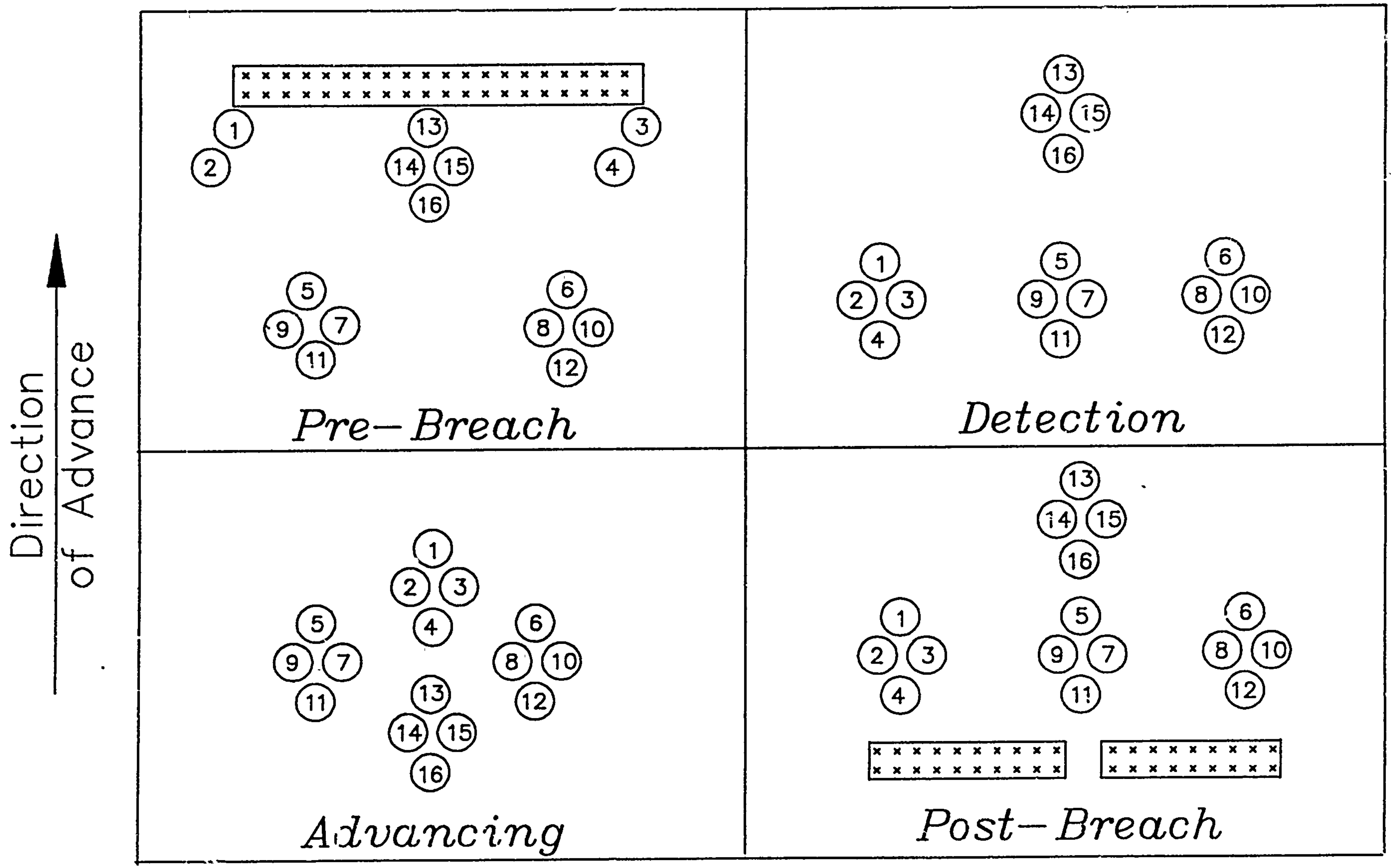

Figure 2. Typical vehicle formations used by MADMM.

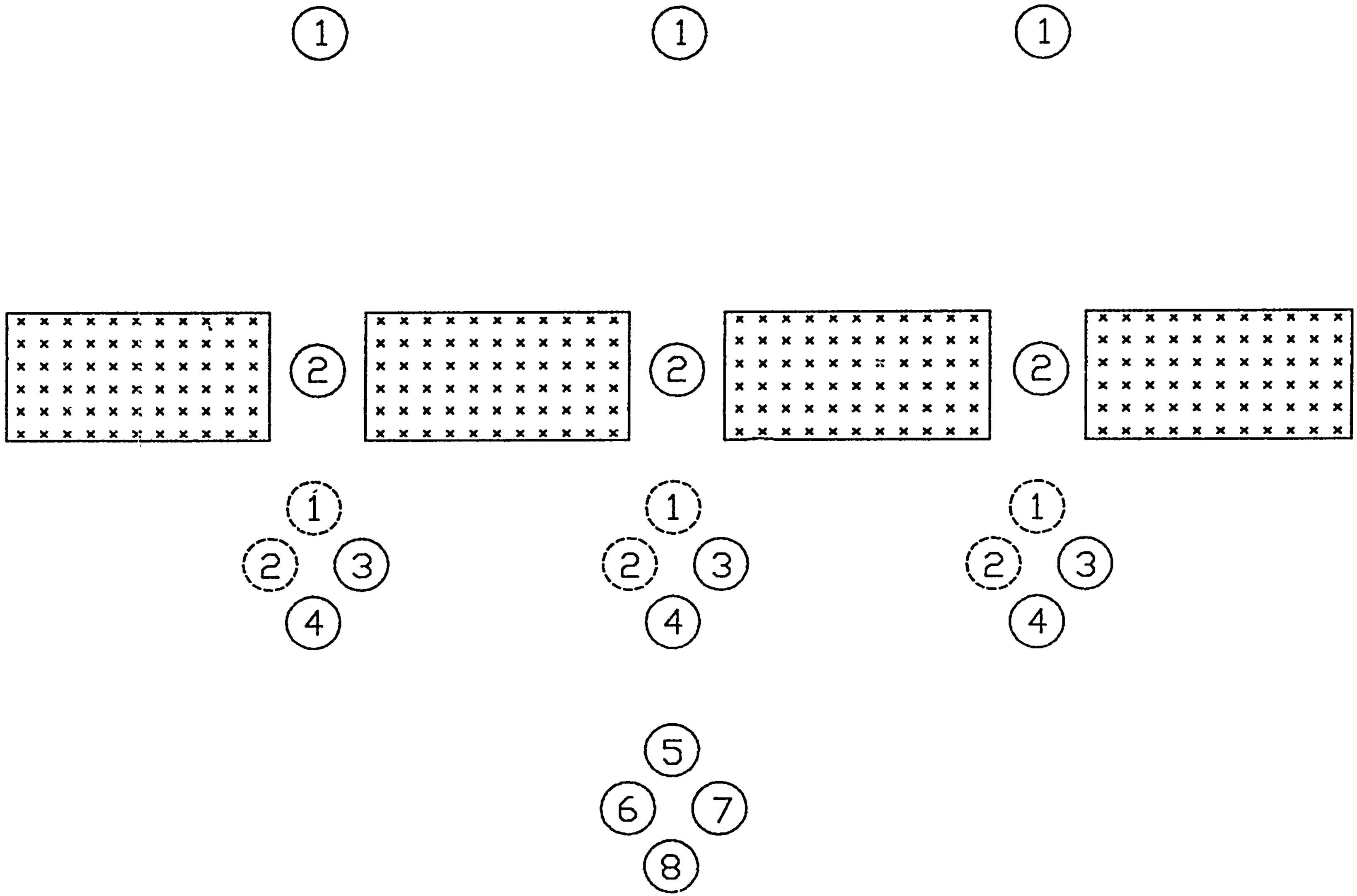

Figure 3. Minefield breach sequencing.

fifth, stationary, formation that is used when the attacking unit's strength drops below a user-specified threshold. This allows the remaining units to continue on toward the objective.

FIRE AND DETECTION

All vehicles may have up to two weapon systems. All weapons start out in the detection mode. If a weapon can detect an opposing vehicle during a given 30-second time step, it fires on that vehicle during the next 30-second time step. Regardless of the outcome, the weapon returns to the detection mode for the following time step. As a control for fire distribution, only two weapons from the defending company may detect or engage any one vehicle in the advancing company while four weapons in the aggressing company can detect or engage any one vehicle in the defending company. The detection calculations take into account such things as the probability of looking in a given direction, the apparent range of the target, the crossing velocity of the target, and the terrain around the target. The engagement calculations are performed using a Monte Carlo model to determine the outcome of the engagement. The range from the firer to the target is computed and used in a range table specific to the firing weapon to determine the probability of a hit. A second table, specific to the firing weapon and the target vehicle, is used to determine the probability of a kill given a hit. These values are compared to random draws to determine the outcome of the engagement.

FUTURE WORK

One of the primary, if not the most critical, areas of future work is model validation. Studies will be performed to validate MADMM using a combination of historical data, training exercise results. and other high resolution models.

In future versions of MADMM, terrain will be represented more accurately. At a minimum, terrain will be expressed in terms of relief and vegetation. This will allow for calculations of line-of-sight (LOS) to more accurately model the direct fire battle, and provide a better means of determining unit speed. The ability to use smoke must also be modeled because of the effects on LOS.

Modifications to the minefields are also on the agenda. The mines are currently uniformly distributed over a rectangular minefield. More complex distributions will be required to model artillery delivered minefields. As mentioned previously, the former can be simulated with Gaussian distributions over an elliptical area. The latter will require a multi-modal distribution to portray the individual rows of mines.

SUMMARY

MADMM is a general-purpose, high-resolution mine/countermine model capable of simulating up to a battalion-sized force advancing along one or more avenues of approach towards an objective defended by a company-sized force. Minefields may be placed anywhere along the avenues of approach and may contain multiple mine types with varying densities. Both defensive and suppressive fire can be included if the user wishes. A graphical preprocessor enables the user to create and modify the input data quickly and easily.

Though originally written to qualitatively validate attrition and delay algorithms in the VIC combat simulation model, MADMM is flexible enough to use for studies in breaching asset allocation, breaching asset effectiveness, minefield effectiveness, or for determining input data for more highly-aggregated models.

ACKNOWLEDGMENT

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Responsibility for coordinating the EMIP program at WES was assigned to Mr. Tommy C. Dean of the Mobility Systems Division (MSD), Geotechnical Laboratory (GL), under the general direction of Mr. Newell R. Murphy, Chief, MSD, and Dr. William F. Marcuson III, Chief, GL. Dr. Paul F. Hadala, Assistant Chief, GL, is the Corps of Engineers, R&D program coordinator for EMIP. Special thanks to MAJ Dave Davis, U.S. Army Engineer School, Fort Leonard Wood, Missouri, and to Dr. Sam Parry, U.S. Naval Postgraduate School for their support and guidance during this work.

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Minefield Effects on Attacking Armor
Some High Resolution Minefield Model Results

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1 Introduction

In 1979, the Review of Army Analysis [3] found several deficiencies in the Army's computerized combat models: poor documentation, poor response of study needs, inconsistent results, differing data assumptions, lack of interface structure, and limited (or no) functional area representation. Thus, a directive was issued for an Army Model Improvement Program in April 1980[1]. The Engineering Model Improvement Program (EMIP) is a part of the Army program designed to ensure that engineers are properly represented in the Army's hierarchy of combat simulation models. The EMIP plan was published by the Engineering Studies Center in 1988 [2]. Major elements of the plan provided for changes to the Combined Arms and Support Task Force Evaluation Model (CASTFOREM), Vector-In-Commander (VIC), Force Evaluation Model (FORCEM), and the development of an Engineer Functional Area Model (EFAM). Priority was placed on enhancements to VIC and the development of a VIC-based EFAM (hereafter referred to as VIC-EFAM).

As it is currently being evaluated, VIC-EFAM makes several assumptions about the effects of a minefield on a unit. It computes casualties and delay suffered by a unit as a linear function of the percentage of the unit facing the minefield, comparing the percentage of the advancing unit (e.g., BLUE battalion, RED regiment) facing the minefield to the number of advancing columns. Delay and casualties are computed based on the "number" of columns blocked by the minefield. Additionally, VIC-EFAM does not model any effect on a unit caused by the "angle of incidence" of a unit into the minefield.

This study was conducted to analyze the impact of minefield size, orientation, density, and emplacement on the attrition and delay of an attacking unit. It uses a high resolution model to gain insight into the effects of the minefield. The results will be used to develop input and validate the existing methodology and algorithms in VIC and VIC-EFAM.

We examine the impact on the rate of advance and casualties of an advancing US armor battalion caused by minefields along the battalion's route of advance. Specifically, we examine the effect of the angle between the unit's route and the minefield, and the number of avenues blocked.

2 The Existing Model

2.1 Design

The High Resolution Minefield Model (HiRMM) [4] was written to examine the various mixes of the track width mine plow (TWMP) and the track width mine roller (TWMR) to determine the optimal type and number of systems that can be effectively used to breach a series of minefields by an armor battalion.

It is a high resolution stochastic simulation of a US armor battalion attacking a defending armor company. Resolution of the model is at the individual vehicle level, with the major emphasis of the model being on the actions taken when the advancing force encounters a minefield.

The simulation is a hybrid time-step/event simulation: it uses a nominal thirty second time step throughout the battle, but examines mine encounters using an event driven logic superimposed on the basic time

[1] The tasks and responsibilities of this program are described in Army Regulation (AR) 5-11 [1].

step. HiRMM is able to model up to two minefields per avenue of advance, and in discussions they will be refered to as the near minefield and the far minefield.

While not dealing with a minefield, BLUE units are modeled as formations dispersed about a control or "ghost" vehicle which advances along a network used to represent the actual terrain. While breaching or bypassing a minefield, the same basic structure of movement is employed, but the time step is subdivided as needed to account for eac' mine encounter. The occurrence of these mine encounters is based on a probabilistic computation of mine placement intervals, rather than on an explicit representation of the minefield.

In its current configuration, HiRMM plays two kinds of breaching equipment, both based on an M1 tank with the addition of special equipment. The two breaching assets represented are the track width mine plow (TWMP) and the track width mine roller (TWMR).

2.2 Implementation

HiRMM is coded in FORTRAN, and its data inputs are file based, allowing for significant changes in the BLUE forces, RED forces, and terrain without modifying the basic model. The specific version used for this analysis has been somewhat rewritten from the code developed for Pijor's master's thesis, primarily to further reduce the amount of data "hard-wired" into the code, and to produce run-time speed improvements. These changes were implemented in conjunction with porting the code to run on a VAX-2 minicomputer rather than the original IBM 3030 mainframe. Aside from two "bug fixes", [2] this port did not affect any of the logic described in [4].

Since one of the specific areas of interest in this analysis is the rate of advance of the unit, the way HiRMM models the effect of sub-unit[3] delays on other sub-units should be carefully examined. Each sub-unit's distance from the objective is computed. If the range difference between the farthest and nearest sub-unit is less than the specified lag distance, then all units proceed at the maximum speed possible as determined by terrain and equipment in each sub-unit. However if the range difference is greater than the specified lag, then the speed of the closest sub-unit is adjusted downward by a lag factor, slowing it somewhat to prevent the unit from becoming too dispersed.

Also relevant to this analysis is the unit's actions on discovering a minefield. The discovery can either occur visually or through a unit detonating initial mines in the minefield. On discovery, by either means, the unit is held in place for an arbitrary period of time (one time step of thirty seconds, in this implementation) and then instantly transitioned to the "breaching" formation. While not a high-fidelity model of a unit's actions on encountering a minefield, this representation served HiRMM's initial purpose well enough. For this analysis, which is concerned with the rate of advance of the unit, this representation is probably oversimplified. Because of the large code changes needed to implement more realistic formation changes, this analysis was conducted using the existing code. This will impact on the magnitude of some of the time changes observed during the analysis.

HiRMM's stopping criteria for the battle are:

- RED force becomes combat ineffective. This occurs when the RED force falls below 25 percent strength.
- RED force is overrun. This is implemented as the minimum range between the two forces falling below 250 meters.
- Simulation time becomes greater than 100 minutes.

These stopping criteria can result in some battle results that are not immediately obvious. Because of the M1's accuracy and rate of fire, it is possible for the attacking battalion to render RED combat ineffective before encountering the near minefield. If this occurs, the output data will reflect that the battle ended quickly, with BLUE at a relatively high range.

[2] In the minefield detection part of the movement subroutine and in array dimensioning for large numbers of repetitions.

[3] In this instance a sub-unit refers to a company-sized element, although any sized element may be examined in the model.

2.3 Tactical Situation

The tactical situation being modeled is a BLUE battalion of four companies, equipped with M1 tanks and minefield breaching equipment, attacking along four avenues of approach against a RED armor company reinforced with BMP fighting vehicles. Each BLUE company consists of fourteen tanks, some of which may mount either track-width mine plows, or track-width mine rollers. The configuration modeled is ten unmodified M1's, two M1's with mine plows, and two M1's with mine rollers. This configuration, usually referred to as 10-2-2, is used for much of the analysis that follows, although other configurations are also examined.

The RED force itself consists of a tank company (10 tanks) reinforced by a BMP-equipped platoon (3 BMPs). In accordance with current Soviet defensive doctrine, the RED force has emplaced two minefield belts, at about 3000 and 1500 meters to the front of the defensive position. These minefields are nominally 150 by 500 meters, and have densities of 0.003 mines/sq. meter (far minefield) and 0.02 mine/sq. meter (near minefield), respectively. The minefields are laid using only single impulse, pressure detonated mines.

The BLUE force has been assigned the mission of conducting a hasty attack, and has elected to put all four companies abreast to attack. The simulation begins with the BLUE battalion approximately eight kilometers from the objective, and the RED force in prepared positions on the objective.

3 Measures of Effectiveness

The principal statistics used to evaluate the results of the simulation were:

- BLUE force casualties. These are available broken down by several categories, but the major figures used are the total kills of all equipment types from all causes (mines and direct fire), and the kills due to mine detonation. Some additional insight into the progress of the battle is gained by examining the number of kills on each of the types of breaching equipment.

- Time to battle termination. While this is the only measure of the unit's rate of advance available, it must be treated with caution, as there are three distinctly different reasons for simulation termination (see Section 2.2).

- BLUE casualties per unit time. A strong correlation exists in HiRMM between time to battle end and total BLUE casualties. This is caused, in part, by the battle termination criteria; even if all BLUE units are forced to halt and assume a defensive posture, the battle will not terminate until either the RED forces have been attrited to twenty-five percent strength, or clock time runs out. Dividing casualties by time to termination attempts to isolate the impact of the minefields themselves from this effect.

Other statistics are derived from these as appropriate.

4 Angle of Incidence

To determine if different angles of approach significantly affected the outcome of the battle, several scenarios, differing in angle of incidence were examined.

4.1 Setup

The minefield was assumed to be a 150 by 500 meter rectangle (See Figure 1). HIRMM does not address the actual minefield width, except to the extent that the entire BLUE formation is assumed to be in the minefield. Since a different angle of incidence would involve traveling a greater distance through the minefield, the depth of the minefield was altered to represent various angles. For example, if the battalion traverses the minefield at an angle of forty five degrees, it must travel 212 meters ($X = 150/\cos(\theta), \theta < 73.3°$). The diagonal of the rectangle, which is the largest possible distance that can be traversed, is at an angle of 73.3 degrees. Therefore, the last angle used in the analysis was 75 degrees. The other angles used were 0, 15, 30,

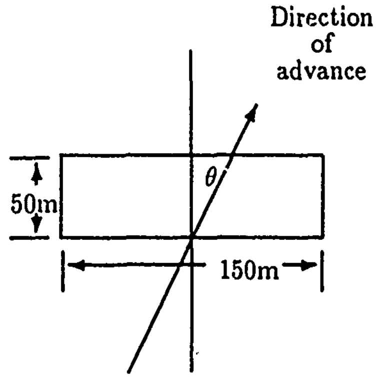

Figure 1: Minefield layout showing angle of incidence.

45, and 60 degrees, which were chosen to give a general idea of any trend that may exist. The corresponding distances are shown in Table 1.

To analyze the effectiveness of the minefield at several angles, three scenarios were designed. As a control measure, two base case scenarios were developed. The first was no minefields and no direct fire. This is developed to find the average time that the BLUE forces needed to traverse the distance between the attacker and defender. The second control measure and first main scenario was no minefields and direct fire from the RED forces. This is used to show the affect of direct fire on the simulation and provide a determination of whether a synergistic effect is present in the simulation, as would be expected in an actual battle.

The second scenario employed all minefields, but did not incorporate direct fire. The third scenario used employed all minefields and direct fire from the opposing forces. The results of the three scenarios will be compared to determine the effect that the minefields had in combat.

The second and third scenarios were run on each angle to determine whether the angle of the minefield had any affect on the simulation. The two base case scenarios were run only once, since angle of incidence into a non-existent minefield is not significant.

4.2 Angle of Incidence Results

Total numerical losses of the BLUE forces were calculated by taking the average value of 100 repetitions for each angle. This value represented the total kills due to both mine detonations and direct fire kills. Figure 2 indicates that there is no significant increase in losses as the angle of incidence increases. There is an increase from about 30.5 kills at 0 degrees to about 31.5 kills at 75 degrees. Of importance is the synergistic effect created when the minefield and direct fire are simultaneously employed. When the losses from scenarios 1 and 2 are added together from the 0 degree to 45 degree band, the losses are approximately 22.5 vehicles. This is contrasted with the losses observed in scenario 3. Although there is a slight decrease in the number of mine losses, the number of direct fire losses rises dramatically, with a combined loss total of approximately 30 vehicles, an increase of over 7 vehicles from the summing of scenarios 1 and 2.

Figure 2 also appears to indicate a large increase in mine casualties at the higher angles when no direct fire is present. The number of losses remains relatively constant until there is a sudden jump at 60 degrees. This is apparently due to the fact that, assuming a 4.5 meter vehicle width, the number of mines expected along the breach path is roughly constant for angles less than 60° and rises steeply to more than twice as many at 75° (see Table 1). Not suprisingly, the mine kills also rise steeply to more than twice as many. This effect holds regardless of the amount or type of breaching equipment. At angles over 45 degrees the minefields are so long that the breaching equipment is destroyed in the minefields, and the remaining tanks are forced to either bull through the rest of the second minefield or bypass it. For example, at 75 degrees, an average of 80% of the breaching equipment is destroyed by the end of the battle. This possibly leaves 3 out of 4 of the companies with no breaching assets. This trend is not apparent in scenario 3 because the

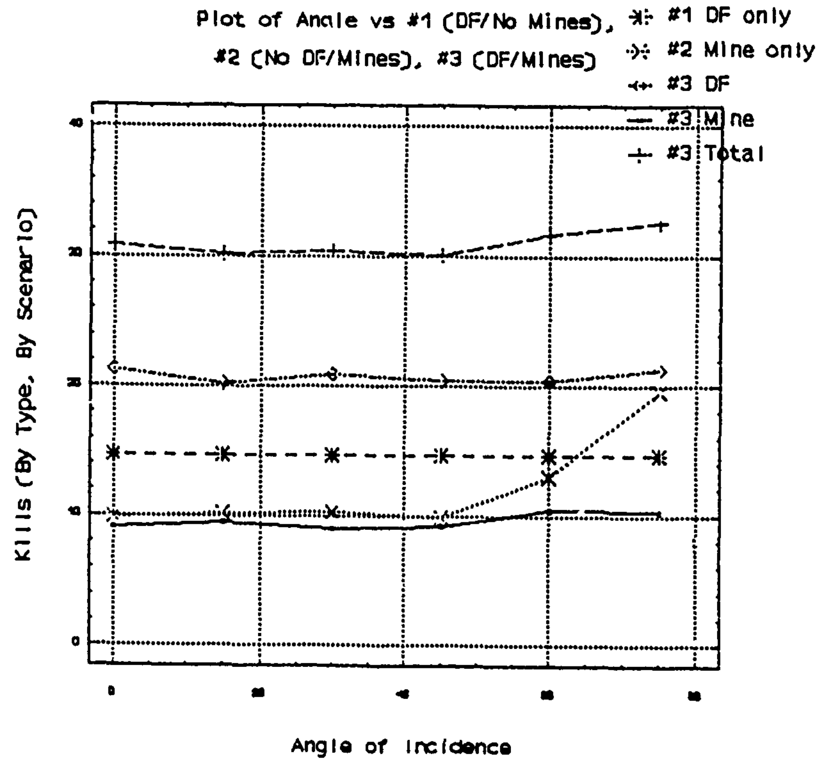

Figure 2: BLUE losses versus angle of incidence.

θ	Depth	Far Minefield	Near Minefield
0	150	2.025	13.5
15	155	2.093	14.0
30	173	2.336	15.6
45	212	2.862	19.1
60	300	4.05	27.0
75	517	7.00	46.5

Table 1: Expected number of mines in vehicle path (vehicle width 4.5m).

losses to direct fire mask the effects of the losses due to minefields. Since there are no direct fire losses in scenario 2, there are more tanks attempting to bull through the near minefield. Thus, the number of tanks destroyed increases greatly in the scenario without direct fire, but the ratio destroyed in the far minefield is about the same.

To determine the time to battle termination, the mean time to battle end over 100 iterations was calculated. The angle does not have a significant effect on time to battle end at the lower angles. Since the minefields probably would not be set up at angles greater than 45° the effect of the jump at 75° will not be apparent in any realistic scenario. Thus, time would be expected to remain fairly constant, as it does, for all of the angles. Moreover, the expected delay would be about the same no matter if minefields are simulated as head on or at various angles.

The reason that the time in the scenario with 100% minefields and no direct fire where the angle is 75° is noticably greater is that the unit has to traverse almost twice as much distance in or around the minefields as at the other angles. At 0°, the unit travels a total of 300 meters through minefields (two minefields at 150 m each) and at 60° it travels 600 meters, but at 75° it travels 1034 meters. This increases the time spent in the minefields either bulling through, breaching or bypassing, because their breaching assets have been exhausted. At the lower angles, the unit has not yet lost its breaching equipment by the time it reaches the second minefield so it will breach or bull through faster.

The third statistic considered was the numerical loss of equipment (vehicles and breaching devices) over time. This is the percentage rate at which equipment was destroyed. The values were first calculated, then averaged over 100 runs.

The rate should stay constant at the different angles if the angles have no bearing on the number of mine kills. In the scenario with 100% minefields and no direct fire, there is a relatively constant rate at which the equipment is destroyed, around 0.22 vehicles per minute, in the band of angles 0°–45°. In this band, the angle does not matter since they are being killed at the same rate, only the time to battle termination determines the number of vehicles lost. The band from 60°–75°, however, has a sharp increase in the rate at which the vehicles are being destroyed, from 0.22 to 0.38. In the direct fire and 100% minefield scenario, the difference is not as apparent. The trend is the same with the first four angles at a relatively constant rate but only a small increase in casualties in the last two angles. One reason for this is that the BLUE force has lost about three times as many of its vehicles compared to losses in the scenario with no direct fire. Thus, while the rate of losses increase at the higher angles after the breaching equipment is destroyed , the change is not as drastic because there are fewer vehicles left to destroy.

4.3 Likely Angles of Incidence

The probability of the higher angles of incidence occurring is slim because of the way minefields are tactically emplaced. Minefields are typically used to tie into other obstacles, either natural or manmade, with the intent of slowing the enemy on a specific avenue of approach. To place a minefield at an extreme angle to the avenue is normally not required to effect this linkage, and is a significant waste of assets if the greater angle is not needed. Enemy units will make their minefields with a greater frontage area and a thin depth, and they will be placed on the likely avenues of approach. Additionally, if an advancing unit is able to detect the orientation of the minefield, even after encountering it, it would normally attempt to breech as short a path as possible through the minefield. Taken in combination, it seems that the *extreme* angles of incidence are relatively unlikely.

4.4 Angle of Incidence Sensitivity

Sensitivity analysis on the angle of incidence was conducted in two major areas. The first was the reduction from two minefields per avenue to one minefield per avenue, comparing the results obtained when only either the near or far minefields (but not both) were emplaced.

In the case of only the far minefield being emplaced, the number of mine kills is higher than those in the scenario with the near minefield being emplaced, however the direct fire losses are lower, with the net total losses being approximately equal in the two scenarios where only one minefield is emplaced. In all cases, scenario 3 (both minefields emplaced) had a greater number of mine kills, direct fire kills and total kills, thereby re-emphasizing the commonly known axiom: employ obstacles in depth. The rate of battle losses was also significantly higher where two belts of minefields were employed. As was seen in the initial analysis, total losses are relatively constant from a 0 degree to a 45 degree angle of incidence, after which a general rise in the number of losses is experienced. The same is true when investigating the rate at which battle losses occur.

The second area of sensitivity analysis dealt with the unit configuration. The base study, as previously discussed, was conducted using a configuration of 10 M1 tanks, two M1 tanks .ith mineplows and two M1 tanks with minerollers for a total of 14 vehicles (10-2-2) per sub-unit and 56 vehicles in the unit. This configuration was analyzed against unit configurations of 12-1-1 and 14-0-0.

Although there are wide fluctuations in the number of losses from direct fire and mines over the various angles of incidence versus the unit configuration. The total number of losses remains relatively constant, regardless of the angle of incidence. The key point to be realized here is that the unit configuration, (i.e. the make-up of the unit) will greatly impact on the number and type of losses the unit will experience. The 12-1-1 configuration proves to be the best, followed by the 14-0-0 configuration and finally the 10-2-2. Thus it is crucial that the composition and, more importantly, the capabilities of the unit in VIC be accurately portrayed in order to evaluate the impact, in terms of time delays and losses, when a unit encounters a minefield.

An obvious dichotomy that needs clarification is the result that a unit with no breaching equipment fairs better than a unit with 2 mineplows and 2 minerollers. HiRMM does not require a unit to breach a minefield if it does not have any breaching assets. Thus, although a higher direct fire loss is incurred, it is not enough to offset the mine losses incurred during breaching operations. Additionally, since the unit is not slowed down in its movement due to the presence of breaching assets, the periods of time when there are no obstacles present, the unit is able to rapidly close with the enemy, thereby reducing the engagement time available to the defending force.

4.5 Angle of Incidence Conclusion

Tying the results in with the VIC model, they seem to indicate that the VIC model is adequate even though it plays all minefield encounters head on. In the band from 0° to 45°, which are the most likely angles at which a minefield would be encountered, the measures remained relatively constant. After 45°, where the length traversed through the minefield becomes much greater, the breaching assets are depleted before the minefields can be cleared. At this point, the casualty rate increases dramatically. The key points which the VIC model must accurately portray are:

- The synergistic effect of the simultaneous employment of direct fire and mines. The effect of casualties when considered separately does not equate to the effects when considered jointly.
- The unit make-up and capabilities must be accurately reflected in order to portray the effects on the delay and casualties inflicted on the unit.
- The effect of minefields employed in depth or zones must be evaluated as a combination of obstacles as opposed to a number of single obstacles employed in the same general location.

5 Percentage of Unit Blocked

5.1 Setup

The presence of minefields on each of the four avenues of approach available makes analysis of the effects of blocking selected percentages of the overall unit relatively simple. To "block" an avenue, the probability of the "far" minefield being emplaced is set to one, and the "near" minefield's emplacement probability is set to zero. Only one minefield (the far minefield) is used to isolate the effect of a single minefield from the synergistic effects of having both a near and far minefield emplaced.

Since there is no reason to believe that all avenues will affect an advancing unit equally, for each of the five percentages examined (0, 25, 50, 75, and 100%), all possible combinations of avenues blocked were run. Differences between avenues can be highlighted or subsumed by examining the results individually

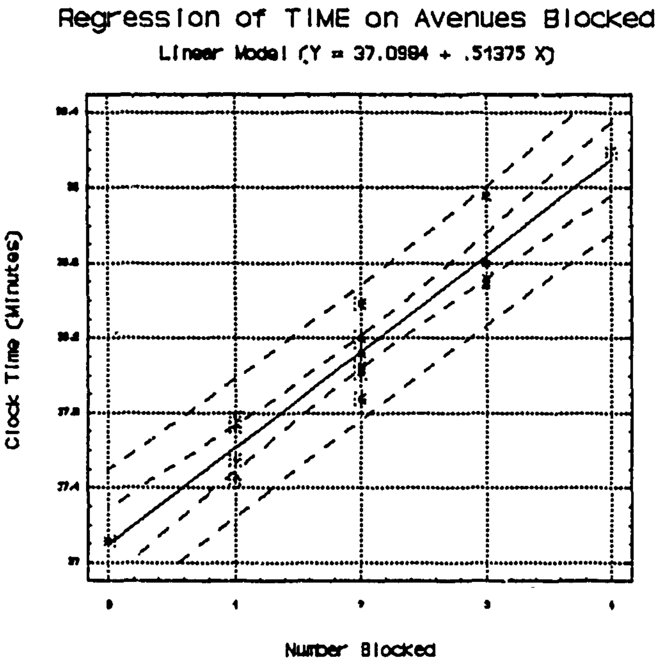

Figure 3: Regression of clock time on number of avenues blocked

or aggregating all blockages of the same numbers of avenues. This approach results in sixteen different scenarios.

For all scenarios, a unit configuration of twelve unmodified M1s, one mine plow, and one mine roller was selected. This represents the "optimum" suggested in Pijor's thesis [4]. This unit configuration is one of the sensitivity cases used for angle of incidence analysis, and hence allows some sensitivity analysis without requiring additional simulation runs.

5.2 Percentage of Unit Blocked Results

An apparently linear relationship exists between the number of avenues blocked and the casualties sustained by the unit, and between the number of avenues blocked and the time to battle end. Since the number of avenues the unit is advancing along remains fixed at four for all cases, the number of avenues blocked maps directly to the percentage of the unit facing a minefield.

Application of simple linear regression techniques to the time to battle end data results in an excellent fit to the data, as shown in Figure 3. The fitted line has the equation:

$$Time = 37.01 + 0.514 Avenues\ Blocked$$

Confirming the visual fit of the straight line, the r^2 for this fit is 0.9195. The differences in times between each step (0 to 25 percent, *etc.*) are statistically significant when only one increment is considered for all steps except from 75% to 100%[4].

A similar analysis of total BLUE kills regressed on number of avenues blocked yields the equation:

$$Kills = 14.48 + 1.87 Avenues\ Blocked$$

This equation has an r^2 value of 0.9062. This fit is shown in Figure 4. Again, the apparently excellent visual fit is confirmed by the high r^2. For each increment, the difference is again statistically significant.

[4] All hypothesis tests are conducted at the 95% confidence level unless otherwise indicated.

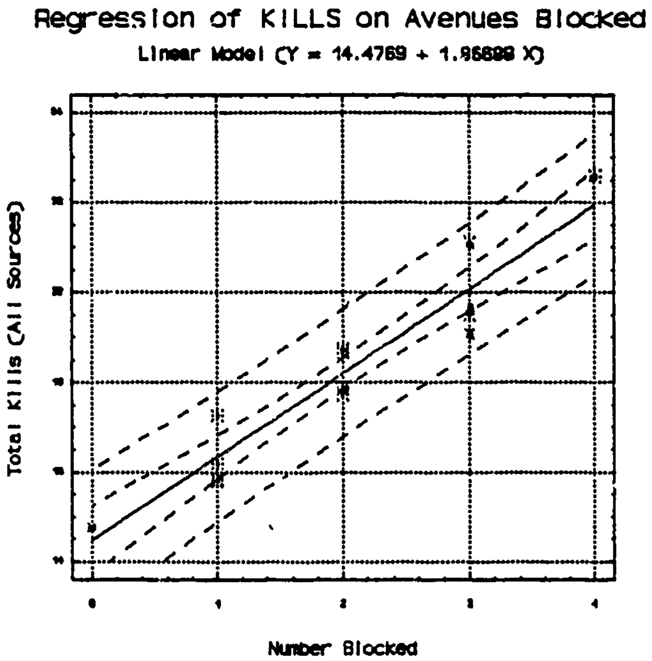

Figure 4: Regression of BLUE Casualties on number of avenues blocked

An examination of casualty rates give similar results: the fitted line is

$$Kill\ Rate = 0.388961 + 0.0423517 Avenues\ Blocked$$

This yields an r^2 of 0.8819.

5.3 Percentage of Unit Blocked Sensitivity

In addition to examining the sensitivity results conducted for the angle of incidence analysis, further runs were made to test the effects of varying density of the minefields. The complete avenue blockage set of scenarios was re-run using a mine density of 0.01 mines/sq. meter. This is an intermediate density, between that of the original far minefield and the near minefield. Based on these results and the results obtained between the near and far minefields, the minefield density does not appear to be a significant factor.

At either density the minefield serves its main purpose, to stop and disrup. the enemy's attack. Mine casualties as a result of this encounter are simply a by-product. With an increased density, the number of discovery kills may increase slightly and the number of losses due to breaching operations may increase slightly. The overall number of losses will increase minimally, especially considering the additional time and material required to increase the minefield density (i.e. the law of diminishing returns). Obviously if the minefield is too sparse, the danger exists that the unit will cross through with no or minimal delay. This paper does not attempt to determine the optimal density, but only discusses the fact that a minimal number of losses are gained by a 10 or 20 fold increase in minefield density.

5.4 Percentage of Unit Blocked Conclusions

It appears reasonable to model both unit delay and the unit casualties in overcoming anti-tank mine obstacles as being linear in the percentage of the unit facing the minefield.

The absolute numbers involved (number of casualties and actual delay) are very dependent on some of the factors built into the model used, and the actual num' rs obtained in this study should *not* be used. This study merely confirms that the functional form involved is sonably linear. Since HiRMM does not consider trafficability effects of slope, soil type, vegetation or vehicle type, VIC-EFAM should probably compute the casualties and time delay for movement unimpeded by minefields and the complete unit facing the minefield, based on the surrounding terrain and unit characteristics, and then perform a linear interpolation between those two endpoints to determine actual delay and casualties.

6 Sensitivity and Conclusions

6.1 Sensitivity

Combining the sensitivity discussions noted above, the following conclusions can be drawn about the sensitivity of the results to various factors:

- The location of a single minefield or belt of minefields does not appear to significantly affect casualties or rate of advance.
- The number of minefields or minefield belts faced by a unit *does* impact significantly on the casualties and rate of advance.
- The density of a single minefield belt does not have a significant effect on casualties or rate of advance.
- The configuration of a unit, with respect to the number and type of breaching assets available, impacts significantly on casualties and rate of advance.
- The presence or absence of covering direct fire on a minefield significantly affects casualties—the total casualties from a minefield covered with direct fire is significantly higher than the sum of the mine casualties absent direct fire and the direct fire casualties absent minefields.

6.2 Conclusions

This analysis has used a high resolution, stochastic simulation model of armor encountering minefields to examine the modeling of rate of advance and attrition of the unit. We conclude that the angle at which the unit encounters the minefield is not significant for reasonable values, and that both delay and attrition are approximately linear with the percentage of the unit facing the minefield.

We also conclude that the location of a single minefield does not significantly affect casualties or the unit's rate of advance. Minefield density does not significantly increase minefield effectiveness provided the minefield is dense enough to ensure that the attacking unit identifies the minefield.

This research also reinforced some accepted principles about obstacle use. The lesson is to employ obstacles in depth, and cover them with fire. The synergistic effect of these principles was vivid in the simulation results.

The number and type of breeching assets also affects casualties and rate of advance. Somewhat unexpectedly, though, more is not always better.

These conclusions support some of the modeling assumptions made in creating VIC-EFAM. The conclusions may also be useful in examining other models; more importantly, the methods used here provide a way to corroborate other combat simulations where the data needed for true validation cannot be found.

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INTERACTIVE UNIT MOVEMENT ROUTE ANALYSIS USING THE CONDENSED ARMY MOBILITY MODEL SYSTEM

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ABSTRACT

This paper describes the methodology, algorithms, and integration techniques used in implementing unit movement route analysis into the Condensed Army Mobility Model System (CAMMS). The objective of this model is to provide the commander or terrain analyst with an analytical tool to rapidly determine possible avenues of approach for units of various sizes and formations. Travel time from the assembly area to the objective is computed for each avenue based on mobility of the unit (acquired from CAMMS) and corridor widths along the avenue.

INTRODUCTION

The CAMMS is a PC-DOS based system aimed at supporting commanders at the battalion level or above with detailed mobility and terrain evaluations. The system generates products known as Tactical Decision Aids (TDAs) which are used in pre-battle planning or during battle decision making. Currently, CAMMS only models single vehicle mobility. The limited use of single vehicle mobility resulted in the development and implementation of a unit movement model. This model will provide a battalion commander with a procedure to select axis of advance, determine phase lines, and define check point positions along the avenue based on the mobility and terrain information readily available to him through CAMMS (see Figure 1). This program will allow units to move along its assigned avenue in route to the objective. The arrival times are computed using the following procedures:

1. Acquire the speed analysis of each company from CAMMS.

2. Compute the maneuver widths along each avenue.

3. Evaluate river and stream crossing(s) along each avenue.

4. Compute breaching times for obstacles.

5. Summarize arrival times of each unit moving along its designated avenue.

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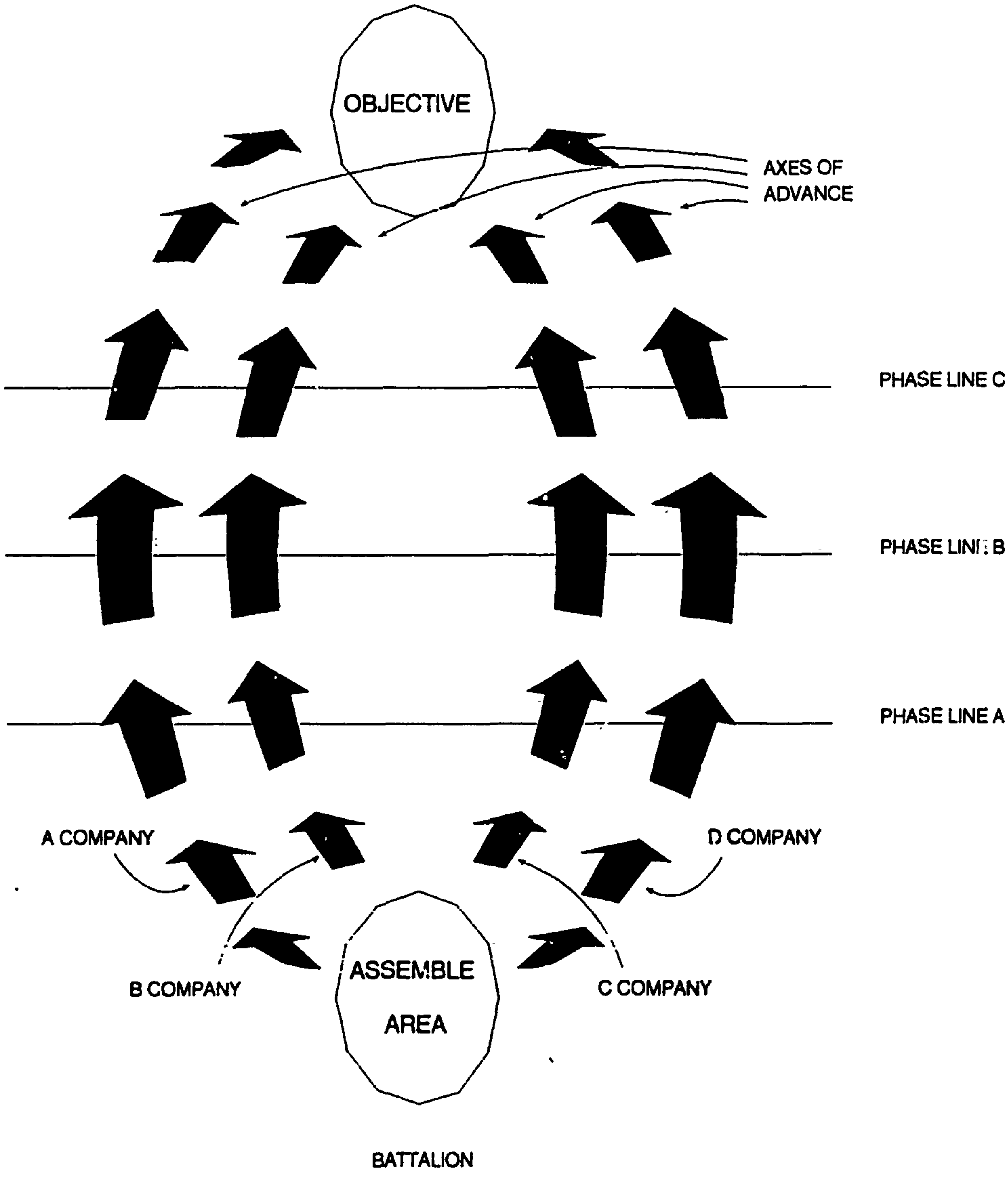


FIGURE 1. CROSS COUNTRY UNIT MOVEMENT IN A COMBAT ENVIRONMENT

Arrival times, choke points, and areas requiring engineering support are displayed along each avenue. If an avenue is then determined unsuitable, the user can select another avenue and revaluate. This process continues until avenues are located that provide the commander the with appropriate times needed to meet his objectives.

DESCRIPTION OF CAMMS

Currently CAMMS version 2.0 provides off-road, on-road, fixed bridge, and river/gaps crossing predictions which are directly influenced by current or historical weather conditions. The current weather is introduced into the system (in 24-hour cycles) through the Soil Moisture Strength Prediction (SMSP) model which accretes or depletes the strength of the soil relative to the terrain characterics and collected precipitation amounts. At that time the user selects vehicle(s) of interest and generates vehicle mobility prediction(s) based on a SMSP prediction, terrain characteristics, and the vehicle specifications. CAMMS can then graphically display any TDAs (predictions or terrain factors) by using a set of graphic options that provides the user with a visual means of evaluating the data.

Interactive TDAs currently implemented in CAMMS include route analysis, tactical bridging, and obstacle emplacements. Route analysis provides the user with a procedure to analyze rates of movement (on- and off-road) for a single vehicle along a desired route. The use of tactical bridges is introduced into route analysis to assist vehicles in crossing gaps (rivers and streams) that are otherwise considered impassible. Along with the ability to define offensive strategies, CAMMS also allows the user to create defensive strategies with the obstacle emplacement procedure. It allows the user to emplace various types of obstacles (wire, tank ditches, minefields, and road craters) in strategic locations to possibly slow the enemies approach, canalize him, or make him mass his forces to create a valuable target (Reference 1).

The software implemented in CAMMS is the product of over 40 years of research into vehicle, terrain, and weather interactions.

UNIT MOVEMENT METHODOLOGY

The conceptual design of this model will simulate units moving in a combat environment only (enemy contact is likely) and will restrict all movements to cross county. Cross-country mobility prediction in CAMMS incompasses traveling off-road, crossing gaps (rivers or streams), and breaching obstacles. This prediction will provide the model with speeds for each unit based on current or historical weather conditions.

Units are represented as a company, with the platoons assigned to the company characterized by an aggregation of vehicles. Platoons move parallel to each other but sometimes are forced by the terrain to move laterally around slow/nogo areas. The user defines the position of the battalion where various numbers and types of companies are released, along the axies of approach in route to their objective. The user is responsible for defining the number and type of companies assigned to the battalion. The types of companies implemented are:

1. Tank Company - consisting of M1A1 and M60 Tanks.

2. Mechanized Infantry Company - consisting of M2 and M113 APCs (Armored Personal Carriers).

3. Motorized Infantry Company - consisting of HMMWV and M977 trucks.

4. Infantry Company - consisting of foot soldiers only.

The user also provides the overall width and depth of each company along with a description of the size and formation of the platoons internal to each company. With this capability, the user can simulate companies moving in column axis or traveling overwatch. The company will then remain in this formation unless constricting terrain forces it to reorient.

Utilizing the interactive graphics, the user defines the assembly area, the objectives, and various avenues each company will use in route to their objective. Using this method of input, factors unknown to the model (such as enemy locations and contaminated areas) and route reconnaissance information can be integrated into the evaluation. After the user has completely defined all necessary inputs, the actual evaluation takes place. One company at a time is moved from the assembly area to the objective over its designated avenue of advance.

Each avenue used in the analysis is defined as a series of line segments describing the movements of the company. In order to relate this to the CAMMS off-road data set, the first step is to define it as a series of grid cells. The algorithm used in determining the grid cells crossed by the avenue was developed by Bresenham. Based on a known grid cell size (usually 100 metres), the algorithm then computes a set of grid cells that best represents the selected route. Units are moved in intervals across each cells define above. After the movement cells are defined, the predicted speeds for each cell is acquired from CAMMS (Reference 3).

The speed predictions used in the unit's evaluation are created in CAMMS. A unit's speed prediction consist of daily predictions of each type of vehicle assigned to the unit. The prediction should be created before entry into the unit movement routine. Each individual vehicle prediction is made for a positive up-slope surface, a negative down-slope surface, and on a zero level-slope surface. The "harmonic" average (i.e., it is assumed that 1/3 of the distance is up slope, 1/3 is down slope, and 1/3 is level) is also provided for use when direction is unknown. The reason associated with the up-slope (the worst case) is stored to help determine the type of engineering support required to move the unit through the area. Therefore, a speed can be associated with any grid cell in the off-road data base. The following table decribes the cross-county reason codes in CAMMS:

Reason	Description
NOGO Insufficient Soil Strength	The soil cannot provide enough strength to support certain vehicle(s) assigned to that company.
NOGO Insufficient Traction	The slope of the terrain in combination with the traction available from the soil will prohibit certain vehicle(s) in the unit from entering the area.
NOGO Dense Vegetation	Certain vehicle(s) assigned to the unit are restricted from this area because of their inability to override or maneuver around the dense vegetation.
NOGO Obstacles	The geometric description of an obstacle located in the mobility corridor immobilizes certain vehicle(s) defined in the unit.

After the speed predictions are acquired, the next step is to compute the width of the mobility corridor along the avenue. Widths vary throughout the corridor due to the mobility requirements of the unit. Locating these positions becomes important in determining possible choke points, computing movement rates, and selected areas where units should move by bounds. Corridor boundaries are determined by spanning along a perpendicular from the initial route (in both directions) until a slow/NOGO area is crossed or the maximum lateral boundary is exceeded (see Figure 2). The minimum unit speed across the movement cell becomes the speed of all vehicles in the unit along that perpendicular line. The proper speed prediction (up/down/level) is applied by comparing the variation in elevation from each grid cell (Reference 2).

Two other factors considered in the evaluation are the unit's ability to cross gaps (rivers or streams) and breach man-made obstacles along the avenue. Each avenue is checked for possible intersections of gaps located in the area. If a gaps exist along the avenue, the gaps crossing model will provide the method in determining the units ability to cross. The model evaluates each vehicle assigned to the unit for its ability to cross the gaps unassisted, and if crossing is possible, it provides approximate crossing times. The minimum crossing time for all vehicle assigned to the company becomes the actual crossing time. If any vehicle is determined a NOGO, a time penalty is assigned relative to the problem(s) encountered crossing the gap. These reasons are described in the following table:

Reason	Description
NOGO Water Crossing	Vehicle must swim to cross gap due to water depth.
NOGO Geometeric Interference	The geometric description of the gaps interferes with certain vehicle(s) ability cross it.

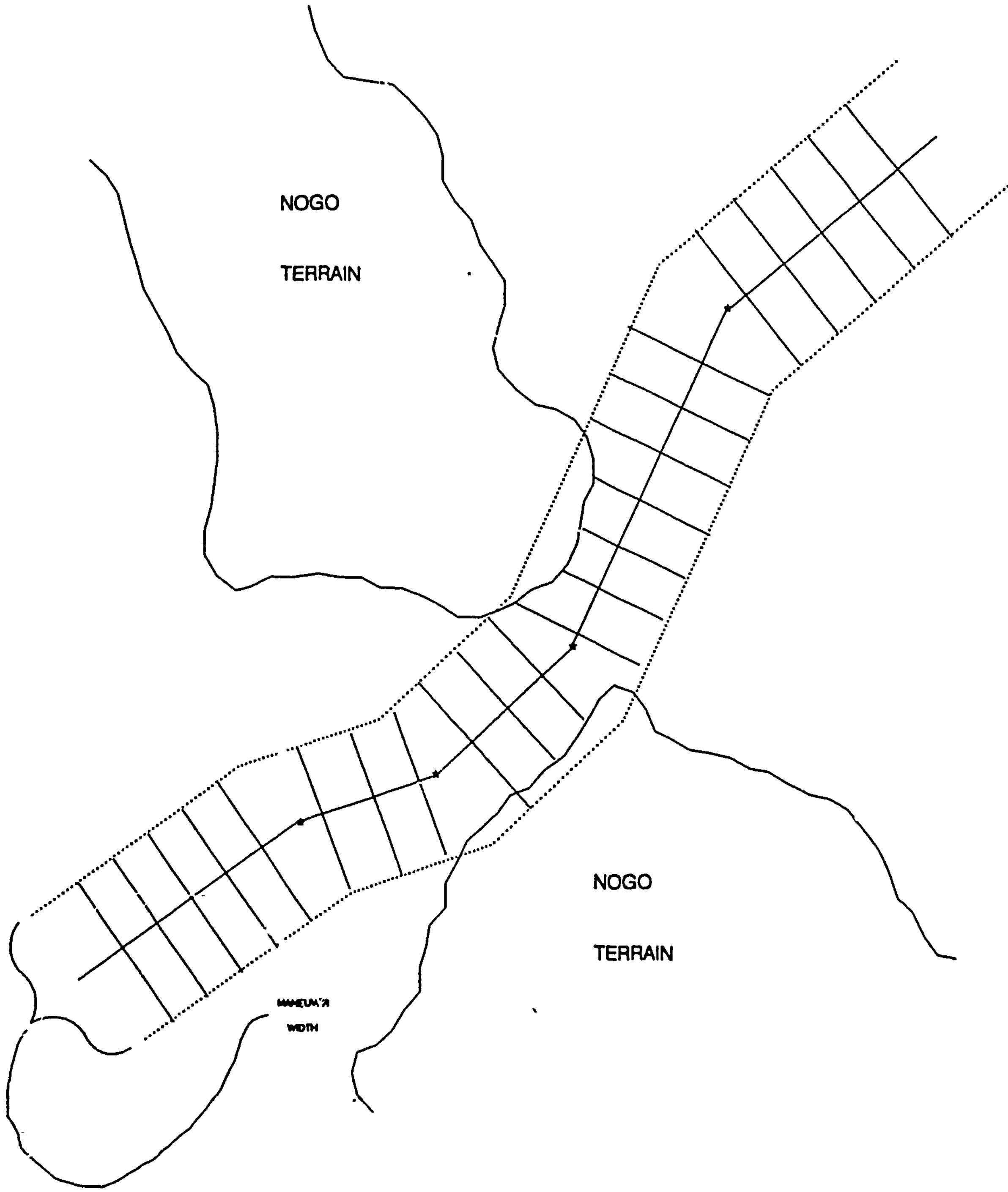


FIGURE 2. DETERMINING AVENUE WIDTHS

Reason	Description
NOGO Insufficient Traction	The slope of the bank angles in combanation with the traction available from the soil will prohibit certain vehicle(s) in the unit from crossing the gap.
NOGO Dense Vegetation	Certain vehicle(s) assigned to the unit are restricted from this area because of their inability to override the vegetaion surrounding the gap.

The avenue is also checked for possible intersections with man-made obstacles defined in the CAMMS database. If an obstacle is located along the route, a breaching time is assigned based on the size and type of obstacle. The obstacle breaching times implemented in CAMMS were derived from the following sources:

1. Engineers School.
2. National Training Center (NTC).
3. 130th Engineers Brigade.
4. Warrior Preparation Center(WPC).
5. Engineering Model Improvement Program (EMIP).

At this point, the following information is known for each cell along the route:

1. Corridor Width.
2. Distance.
3. Unit's Predicted Speed.
4. Unit's Predicted Reason.
5. Gap-Crossing Time Penalty (if gap exist).
6. Gap-Crossing Reason (if gap exist).
7. Obstacle Breaching Time (if obstacle exist).

The final process involves moving the unit along the route and summarizing times using the information compiled above. Along the avenue the units may sometimes have to change the initial formation because of mobility restrictions of the terrain. The corridor width is used in relation with the company width in locating possible choke points as described on the following page.

$$\text{percent choke} = \frac{\text{corridor width}}{\text{company width}}$$

Percent choke is used to determine the movement rates through the corridor. Using this factor, companies are move through the corridor in three methods: bounding overwatch, restricted movements, and nonrestricted movements. Listed below are the conditions dictating which of these methods are used.

1. <u>Bounding Overwatch</u>. If percent choke exceeds the bounding overwatch constant, the company will move through this area in bounds. Caution is used while moving through this area due the lack of lateral movement in the corridor. One unit at a time is moved through the choke point, while the others provide enemy cover. After all the units have moved through the area, they reorganize into their initial formation and continue (Figure 3).

2. <u>Restricted Movements</u>. If the bounding overwatch method is not used and the percent choke is less than one, the units speed is somewhat slower than the speed predicted by CAMMS (CAMMS predicts for maximum speeds). A reduction in speed is applied to account for the reformation of the company moving through the narrow corridor. Because some companies operate better than others, different reduction factors are applied toward each company based on its overall movement skills.

Given that the speed of the company does not decrease as the corridor width decreases, it would be desirable to develop a function which seems to describe the pattern by which it decreases. The following function provides a reasonable approximation of the speed reduction due to constricting terrain:

$$\%\ \text{speed reduction} = \frac{1}{a} * \text{percent choke}^{\wedge b}$$

where

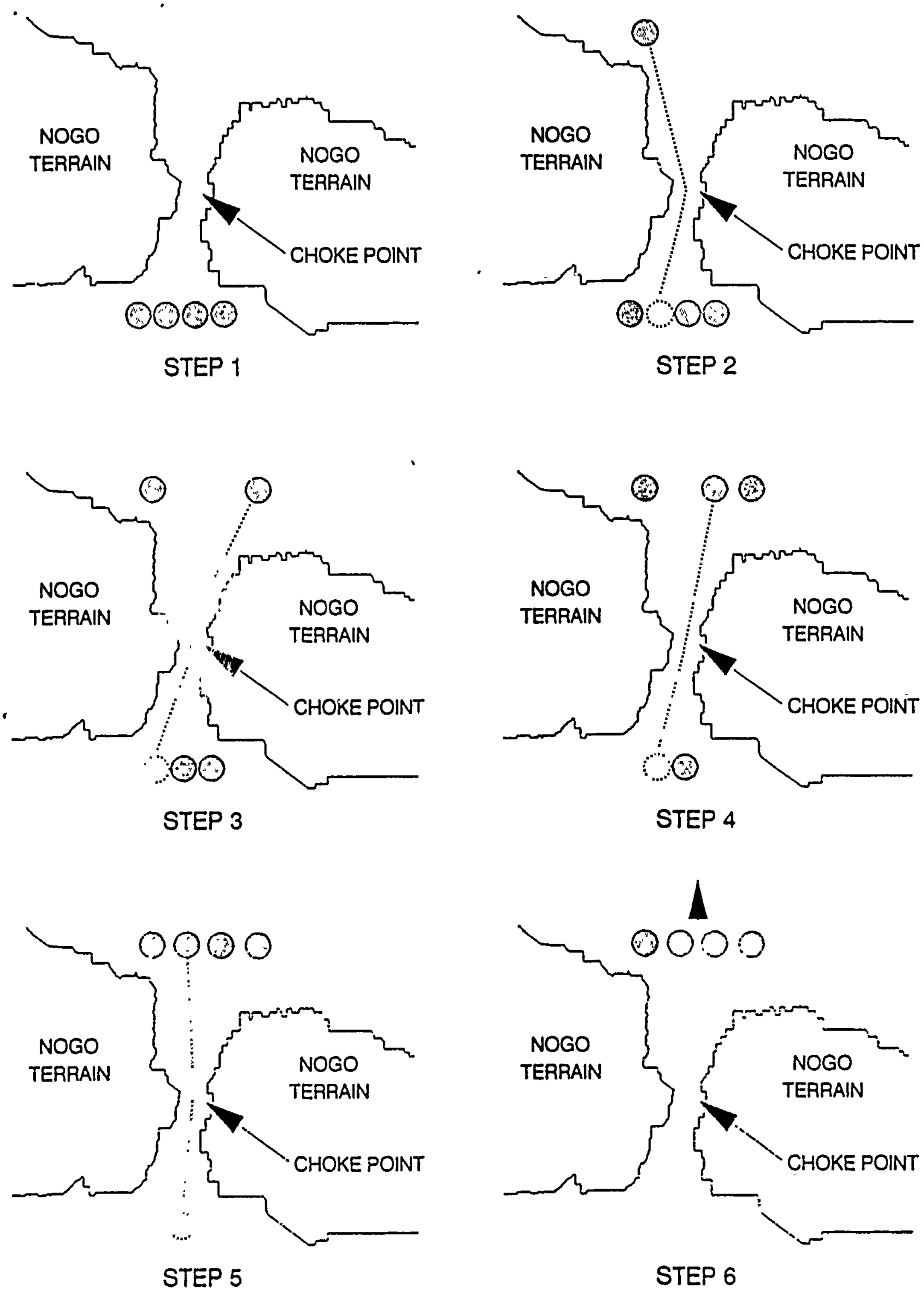
percent choke = Change in corridor width relative to company width

a = A coefficient describing the degree of caution the unit should move through the narrow corridor due to factors not considered by the model (such as known enemy locations, cover and concealment, troop ability, smoke, etc.)

The speed reduction function described above is graphically illustrated in Figure 4.

3. <u>Non-restricted Movements</u>. If the corridor width is large enough not to restrict the movement of the company (percent choke > = 1), the predicted speed from CAMMS is used in computing movement rates.

Once the evaluation is complete for all the companies, intermediate and arrival times are posted along each route. At that time, the user determines



LEGEND

- PLATOON

- PLATOON IN MOTION

FIGURE 3. COMPANY MOVING BY BOUNDS

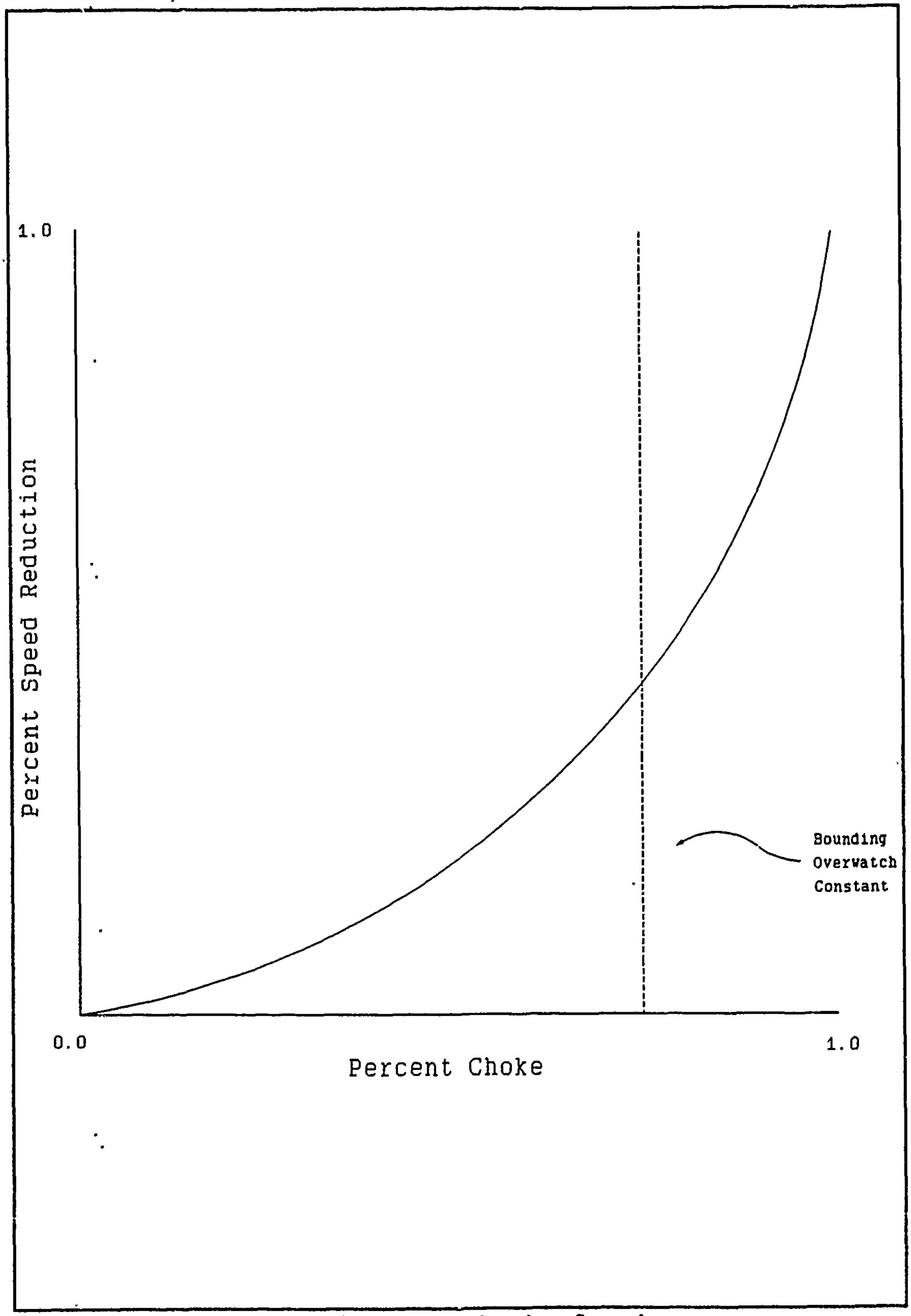


Figure 4. Speed reduction function

if each company arrived at the objective within their designated time. If any times are unsuitable, the user can select other avenues and revaluate.

CONCLUSION

The procedure described above is an initial method of implementing vehicles moving as units in CAMMS. Areas needing future research toward this include the effect of terrain and weather, river crossings, and breaching mine fields. These effects and others will be studied by using the ingres mission data base data acquired from NTC. The intregration of this data with CAMMS will provide a visual representation of actual vehicles moving across a CAMMS predicted speed maps.

ACKNOWLEDGEMENT

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Special thanks are due to Major Monte Pearson, PhD and Dr. John Farr for their contributions toward the unit movement methodology implemented in this program.

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COULD COST ANALYSIS: WHAT IS IT? HOW SHOULD IT BE DONE?

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OVERVIEW AND INTRODUCTION

In his Senate Confirmation Hearings in November, 1987 Dr. Robert Costello, USD(A) advocated a change in the way DOD does business, which would provide substantial reductions in the cost of developing and producing defense systems and military products. He calls this methodology "Could Cost". To demonstrate this methodology he has tasked each of the Service Departments to initiate a demonstration project in their area. The Army chose the Bradley Fighting Vehicle, the Navy the Trident D-5 Missile Program; and the Air Force the B-2 Advanced Technology Bomber. The Defense Systems Management College (DSMC) became involved in this effort when we were asked to assist McDonnell Douglas Helicopter Co. and the Army Aviation Systems Command (AVSCOM) in performing a Could Cost analysis of the eighth production buy of the Apache Helicopter. While this analysis has not been completed as yet, the author has received many requests for further information about how to perform a Could Cost analysis. This report attempts to provide such guidance by considering the following topics listed in Figure 1.

* * * * * * *

* WHAT IS "COULD COST"
* HOW TO DO A "COULD COST" ANALYSIS
  - TECHNICAL ASPECTS
    - -- FRAMEWORK FOR ANALYSIS
    - -- NEED FOR COST BASELINE
  - BEHAVIORAL ASPECTS
    - -- NEED FOR DIALOGUE BETWEEN GOVERNMENT AND CONTRACTOR
    - -- NEED FOR INCENTIVES TO CONTRACTOR

Figure 1. Topics to be Covered in Paper.

* * * * *

WHAT IS "COULD COST"?

The first step that I was faced with in assisting the Apache effort was to formulate an approach to doing a Could Cost analysis. This involved the following efforts: 1) finding out how Dr. Costello defined "Could Cost"; 2) formulating a "first cut", proposed approach to meet the objective; 3) networking among various organizations to test, validate and improve this approach.

To ascertain what Dr. Costello had in mind regarding "Could Cost" I read through his testimony to the Senate Armed Services Committee as part of his confirmation hearings of November 19, 1987. After formulating a tentative approach to conducting such an analysis, I contacted several members of Dr. Costello's office, specifically Bob Davis who has been designated OSD Point of Contact, and Rick Sylvester. I next contacted the OSD Cost Analysis Office, and finally arranged a visit with RADM Ken Malley, Program Manager of the Strategic Systems Program to discuss his approach to performing a Could Cost analysis of the D-5 Trident missile system.

Here are the essential points which make Could Cost different from other related approaches to cost reduction.

Could Cost is a cooperative effort between the government and a contractor aimed at improving the way we do business. It is a way of determining what a system would cost if we could write contracts to minimize the non-value added work done by a contractor. It is a way of achieving the advantages of competition when we are in a sole source procurement environment (although the approach can also be used in a competitive environment). It is more that the "should cost" approach DOD has used in the past in sole source negotiations with the contractor.

Basically, a Could Cost Analysis consists of a reexamination of the total acquisition process with the aim toward improving this process so as to arrive a lower cost, quality product. Here is a definition that the Apache team arrived at:

> "Could Cost is a cooperative government and industry process of eliminating all non-essential effort (labor, material and other costs) while ensuring at the same time product performance and quality".

There is a consensus in performing a Could Cost analysis we should focus on three different ways of reducing cost. The first is a reexamination of the system specifications with the objective of eliminating any "gold plating" or less essential specification which contribute little to the accomplishment of the military task objective. The second way of reducing cost is to determine the most efficient, feasible way of performing the development or production work process, as opposed to continuing the previous work process. This method is essentially the proper way of doing a Should Cost Analysis as has been demonstrated in a number of DOD demonstration projects such as those reported upon in the 1987 DOD Cost Analysis Symposium. The third way of reducing cost essentially involves "Streamlining"; that is tailoring or interpreting the various directives and regulations associated with the way the government acquires systems.

OPERATIONALIZING THE COULD COST ANALYSIS PROCESS

To aid us in examining these three analytical methods, let us refer to a structure I use at DSMC to model our current acquisition process and I find helpful in generating system improvements. As shown in figure 2, we currently acquire systems through a Management Control process in which we divide the entire system acquisition process into a series of phases (Concept Exploration/ Demonstration, Demonstration/Validation, Full Scale Development, Production Deployment, Operations and Support. In this way, as each phase is completed higher level DoD management can conduct a review to validate that the phase has been satisfactorily completed and hence the program can proceed into the next phase of the sequence.

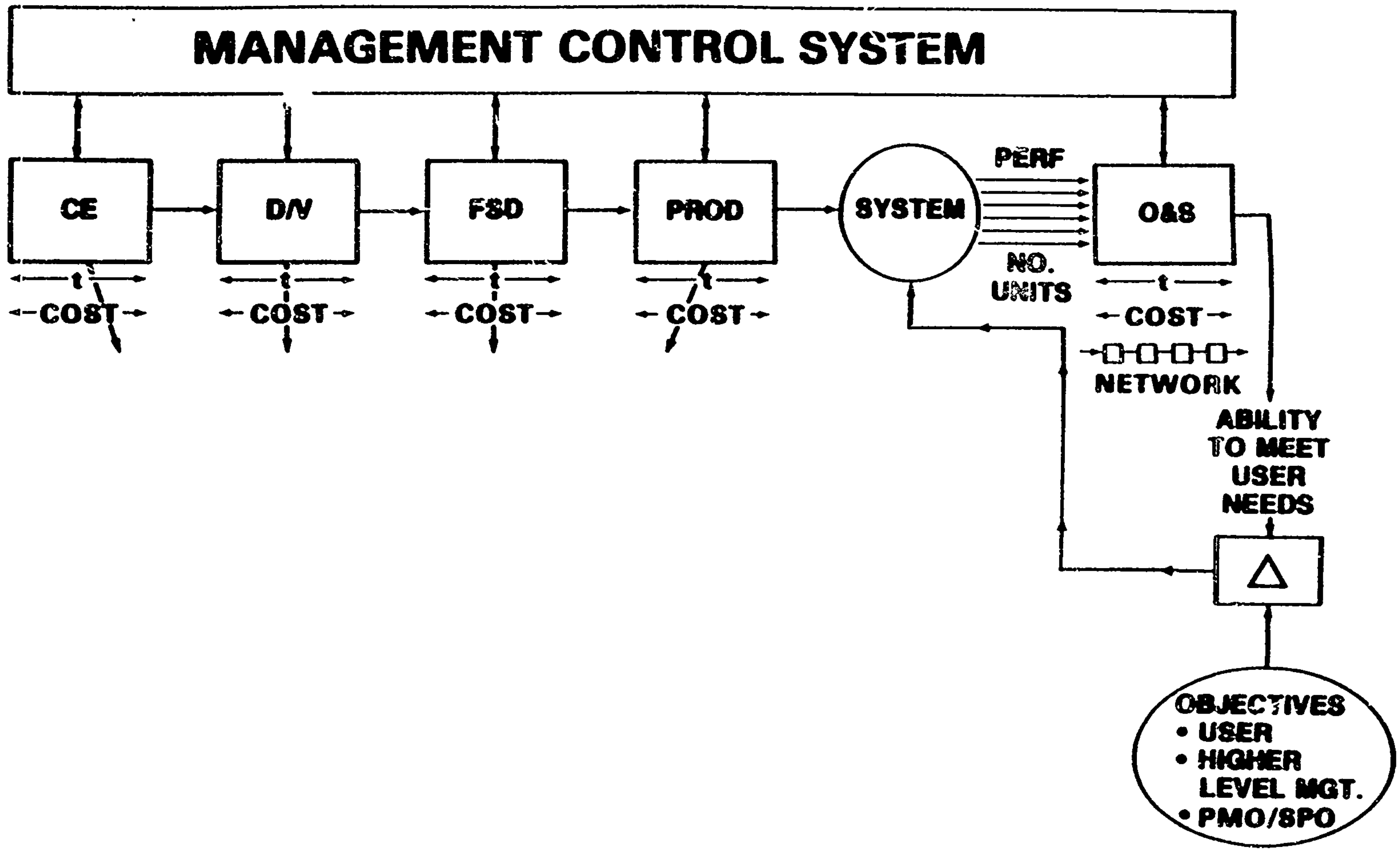
The key principles coming from figure 2 are as follows:

1. Starting with the concept exploration phase, there exists a user objective to be satisfied. This objective is to provide a system which will perform a given military task(s) by a given schedule (e.g. IOC).

2. The objective of higher level management is to make certain that the user objectives are satisfied, and that the system is affordable.

3. The objective of the contractor is to perform the necessary system design trade-offs such that the set of performance characteristics obtainable in the field and the number of system units required will meet the user objective at lowest total cost (generally present value life cycle cost), taking into account risks and uncertainties.

4. The objective of each succeeding phase is to continue the development and testing process, so as to validate the set of specifications which the system will ultimately provide in the field. If there are major changes in later estimates of achievable performance characteristics, it is the responsibility of the contractor to perform new trade-off analyses so as to arrive at the lowest cost way of meeting the user objective. Thus the contractor is periodically modifying his estimates of



WORK PROCESS IN SYSTEMS ACQUISITION

Figure 2

performance, schedule and cost for each succeeding phase in the acquisition process.

SUPPORTING MODELS

One of the management requirements to be provided at the end of each of these phases is an estimate (or reestimate) of the time and cost of each succeeding phase in the acquisition process for purposes of program planning and budgeting and control. To aid the contractor in making such estimates he can use the following analytical tools, shown in figure 3.

1. A Work Breakdown Structure (WBS) which lists in hierarchical form the various hardware and software deliverables to be furnished during this phase, and the performance or quality standards associated with each deliverable.

2. An Organizational Breakdown Structure (OBS) which lists in hierarchical form the contractor's organization to be applied to each phase.

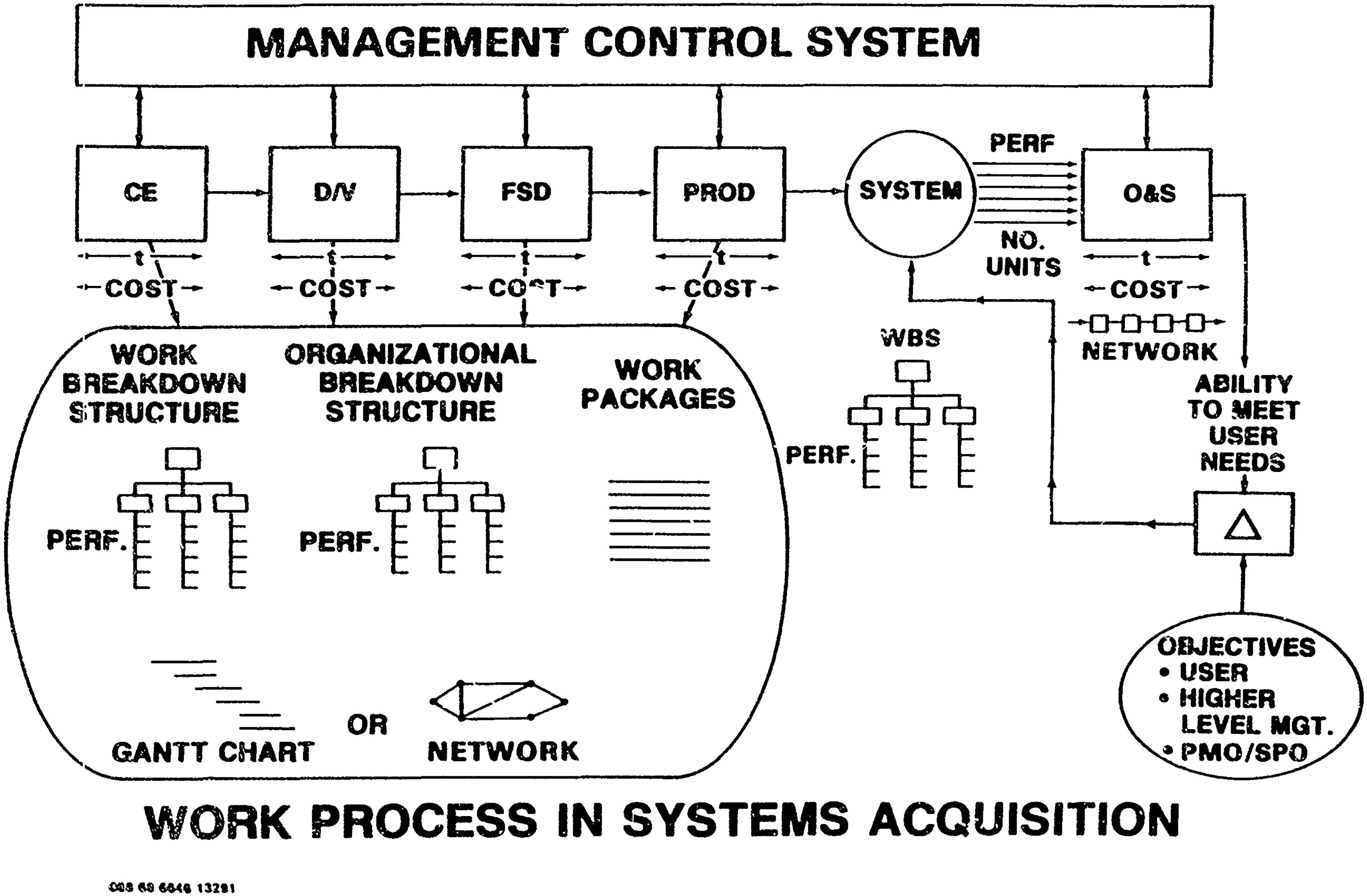
3. A set of work packages (sometimes called tasks or activities) which need to be accomplished to generate the contract deliverables.

4. A cost estimating technique. The cost of each phase may be estimated in one of several ways, depending on the data available. A "bottoms-up" cost estimate may be made by considering what elements must be purchased (eg. subcontracts, new tooling, development, test and production equipment required). These elements can be identified from the organizational breakdown structure as well as the set of work packages. Other bottoms-up costs may obtained from the work packages associated with the development or production process. These costs include the cost of labor, material and other direct costs for each work package, as well as overhead costs. Operations and support costs can be estimated from a network representing the operations and support process to be followed. Of course in certain early phases the use of analogy or parametric cost estimating techniques might also be used to estimate costs.

5. Delivery schedule may be estimated using a Gantt chart or network which arranges the work packages in time sequence (or by interdependencies). Having a network permits the use of Critical Path Scheduling techniques. Alternatively, parametric equations may also be used to estimate schedule if sufficient data relating performance characteristics to schedule is available.

USING THE STRUCTURE

We shall now show how to use the structure of figure 3 to focus on each of the three opportunities for reducing system cost



MANAGEMENT CONTROL SYSTEM
CE
D/V
FSD
PROD
SYSTEM
PERF
NO. UNITS
O&S
t
COST
WBS
PERF.
NETWORK
ABILITY TO MEET USER NEEDS
OBJECTIVES
• USER
• HIGHER LEVEL MGT.
• PMO/SPO
WORK BREAKDOWN STRUCTURE
ORGANIZATIONAL BREAKDOWN STRUCTURE
WORK PACKAGES
GANTT CHART
OR
NETWORK
WORK PROCESS IN SYSTEMS ACQUISITION

Figure 3

as previously described. The first step in this process is to generate a system baseline since all analyses will be performed on a relative basis; (ie. comparing a proposed alternative course of action vs. the current system baseline to see if lower costs result). In the case of Apache, the specific baseline was defined as a proposal being currently generated consisting of the eighth production buy of Apache for FY 1989. The performance characteristics, including all government regulations and directives to be followed, has been specified by AVSCOM. The production process and a cost estimate for this production lot is being generated by McDonnell Douglas.

I. Revalidation of Performance Specifications. We shall now consider the first thrust of a could cost analysis: revalidation of performance specifications. In the case of the Apache production proposal, there is to be no change in the performance specifications at this time. However, if there were to be changes in the specifications, here is how they could be evaluated. For example, next year an Apache Modernization Program will be proposed, consisting of a series of improvements (changes in specifications) which presumably are cost effective. Under a Could Cost analysis each of these changes in specifications could be analyzed in the following way: First, list the proposed improvements which are being proposed. Next indicate the various benefits over time associated with each change. Next indicate the various costs over time associated with each change. Finally, relate benefits to cost.

Let us consider examples of how these benefits and costs can be quantified and evaluated against one another, using the techniques previously described.

A. Parts Corrosion. Apache is considering a redesign of certain parts whose useful life is being deteriorated through corrosion. Two types of benefits are available. First, existing corroded parts require part replacement (or certainly overhaul) more frequently than an improved part which does not corrode. Thus comparing the improved part vs. the baseline part indicates cost savings in labor and parts due to a reduced frequency of replacement over an assumed life cycle. In addition, each time there is a repair or replacement action there is some down time in which the system is not available, thereby reducing Operational Availability or Readiness Rate of the system. Thus the second benefit of an improved system is the increased availability rate which could be translated into less aircraft to be procured to meet a given specified availability rate, than the baseline system. Thus down time can be translated into additional effective savings of having to procure less aircraft to meet a given mission requirement.

B. Improved Fault Detection/Location Equipment. This improvement consists of various sensors which detect when a part fails and the location of this part. Here we compare the savings in maintenance time for an improved maintenance system vs. the baseline in terms of the manpower time saved in detecting and locating a fault. (Of course, the false alarm rate of replacing a wrong part must also be considered). As in the previous example, this savings in time can be converted to savings in labor cost as the primary cost savings. In addition, the improvement in availability rate should also be converted into effective savings in procuring less equipment as previously described.

To evaluate the cost effectiveness of each proposed change, the cost associated with each improvement must also be considered and compared against the benefits on a total life cycle cost basis. Cost vs time can be estimated by using the tools shown in figure 3 as follows:

What is the current status of the proposed improvement? Has it been completely developed and hence only needs to be produced and installed, or is additional development required? What cost savings will the proposed improvement provide over its assumed operational life? From these analyses we can develop a cost-benefit stream. From the development/production network we can construct the initial cost stream (of development, production and installation) of investment costs to be incurred before operations. This is followed by a benefit stream of the total estimated savings over an expected life of the improvement. From this one can develop two cost-benefit measures. The first consists of the present value net savings of the entire cost-benefit stream, using a discount rate (say 10%) provided by OSD. This measures the total net benefits of each proposed improvement.

A second measure is the Savings to Investment Ratio (SIR), defined as the ratio of the discounted net benefits to the discounted investment costs. This method is a good way of ranking a series of proposed improvements where there is a limit on investment costs available.

While we have considered the impact of possible changes in the specifications on cost, it should be noted that many times changes are proposed too late to have any beneficial effects. For example, the Trident Program was asked how much savings would there be if the accuracy of the missile were reduced. The answer is that there would be no savings! The development has already been completed and the missile is in production. Any savings in recurring production cost would be counterbalanced by the cost of additional development and testing and perhaps non-recurring production costs .

Extending this principle further, when can the maximum cost savings be achieved by "scrubbing of requirements"? There is an old saying that 75 - 85% of all costs are locked in when the Concept Exploration phase is completed. Thus it is most important to place closest attention to scrubbing the requirements early in the acquisition process. This involves focusing on the military task to be done and validating the operational constraints which the user is placing on the system. Then various trade-offs are made to find that system which requires the lowest life cycle cost to meet the military task and operational and affordability constraints.

II. Should Cost Analysis. The second thrust of a "Could Cost" analysis involves a "Should Cost" analysis. I have found some difference of opinion regarding how this should be done. Some think that Should Cost involves merely assuming that the same work process will be continued into the next phase and that the only improvement is the assumed learning or improvement curve extended out for later production quantities. This is an incorrect definition of Should Cost since it assumes that the same work process will be followed. A true Should Cost analysis involves a team of trained industrial engineers and others critically reviewing the proposed work process (shown as the network or Gantt Chart of figure 3) and identifying improvements which could be made to these work process so that perceived inefficiencies will not be continued. Thus immediate reduction in recurring costs can be made, in addition to future learning/improvement curve improvements for subsequent quantities.

III. Improvements From Streamlining. The third thrust of a Could Cost Analysis involves a reexamination, tailoring and interpretation of acquisition directives and regulations which the government places on the contractor during the acquisition process. This is an represented by the box labeled Management Control System in figure 3. Examples of potential cost savings include the use of multi-year contracts which permit optimal production rates and economic ordering quantities. McDonnell Douglas also indicated they were subject to 1500 audits last year, requiring an average of 25 contractor personnel to service each audit. Quality assurance inspections are being conducted first by the Contractor and then repeated by the government. For their commercial work this is done only once. While they realize that each inspection performed reduces the risk to the government McDonnell Douglas indicates they would be willing to remove this risk by providing a contractual warranty for their quality which would warrant both performance and failure rates by paying for any lack of performance and deficiency in operational availability rate. Such warranties would motivate the contractor to build quality into the work process to avoid such extra costs.

They also claim certain reports they now generate as CDRL's no longer are being used, yet they still must provide them under the contract. Some times data in the Contract Performance Reports (CPR) have unnecessary detail. For example, except for high risk elements is it required to report below the third element of the WBS?

The contractor was able to propose a number of ways of reducing the cost by better tailoring the government acquisition regulations, thus giving the contractor relief of what he considers low value acquisition regulations. It was recommended that the government can evaluate each of these alternative options in the following way:

1. The contractor estimates the cost of doing business under existing regulations and directives. (This is their baseline proposal responsive to the current RFP for the 1989 buy).

2. The contractor lists the series of changes or modifications in directives, etc. which he feels will reduce his (and perhaps also the government's) cost of doing business, and an estimate of the cost savings which may be obtained.

3. The contractor reviews these proposed changes and costs savings with AVSCOM who can decide which ones are worth pursuing in further detail.

4. The contractor makes a final, more accurate, proposal of the cost reduction associated with each of the acceptable options.

In the Apache analysis, McDonnell Douglas was able to generate some 147 high potential cost-reduction candidates, of which 58 were accepted by AVSCOM for further detailed analysis.

BEHAVIORAL CONSIDERATIONS

Having described the technical aspects of conducting the three facets of a Could Cost analysis, let us now consider some of the behavioral aspects in obtaining improvements to the way we do business, including the forces which either aid or prevent these from taking place.

1. The process described involves an effort from both the government and contractor sides of the systems acquisition team, as will be seen. Full benefits can only be obtained if both sides are pro-active in the process.

2. Modifying the requirements appears to be a fairly continual process over the acquisition cycle as new ways of improving the system in a cost-effective fashion are generated. It is in the contractor's financial interest to generate such improvements and he will continue to do so. However, it should be noted that the most important time to "scrub the requirements" is in the Concept Exploration phase before the key system characteristics (and costs) are "locked in".

3. The contractor will readily generate sensible recommendations for streamlining, particularly if he is also in the commercial business such as McDonnell Douglas Helicopter

Company. They have a commercial baseline of the way they do business commercially which they can use to compare against the AVSCOM directives. Hence they can readily estimate the costs savings which could be achieved by tailoring such acquisition specifications. They feel they lose nothing in making such changes and it makes their product more affordable. Here the key is for the government to construct the contract so as to motivate the contractor to produce a quality product as lower cost; i.e., by making him pay for any defects and loss of availability levels below what is normally expected under the current system baseline.

4. Let us now consider the various behavioral pressures on a contractor which motivate him to make changes to reduce the cost of his work process (Should Cost aspects). In a competitive environment, he is greatly concerned with his proposed price, since this effects winning the contract and market share. Hence there is a strong pressure to improve his proposed cost. However, in a sole source environment (say, a follow-on production contract), the current acquisition process may force the contractor into the following business strategy which is counter-productive to Could Cost:

1.) Don't look for cost reduction improvements to his work process before the contract is actually signed;
2.) Propose the highest cost work process he can justify i.e. (continuation of the previous work process used and the highest learning/improvement curve slope he can justify);
3.) After a firm fixed price or incentive type contract is signed make appropriate efforts to reduce cost.

Here are the reasons which push the contractor toward such a strategy. Given that the contract type is probably firm, fixed price or incentive type, he would like the final price or target cost to be as high as he can justify, since his final profit is based on negotiated cost and any improvements he makes during implementation. Also he knows the government will insist on negotiating a learning/improvement curve, which will require subsequent improvements just to make target cost. So why propose many cost reduction improvements initially? Furthermore, why should he even begin any analytical efforts to improve his system before he starts the contract? Under the Truth in Negotiations Act, he must disclose any improvements he might make later and this will be used against him in negotiations. Thus, it is to the contractor's advantage to delay the improvement analysis until start of contract. For these reasons, in a sole source environment I feel that is essential that a Should Cost analysis of the contractor's work process take place. And the government should take a pro-active lead in the Should Cost effort by reviewing the contractor's proposed work process and making recommendations for improvement based on the government's knowledge and experience in this area (including a knowledge of what other contractors are doing in this area). In this way the government can drive the target cost down in a reasonable, acceptable fashion, and the contractor will share in any additional cost reductions he can generate. However, this effort requires that the government have access to experts with experience in the areas under review.

In the absence of a government Should Cost team I believe we need to change our acquisition system to find some way of rewarding the contractor for reducing the cost of his work process as compared with a baseline of his previous (current) work process as audited by DCAA. In this way, the contractor could be motivated to generate cost improvements in time for making his initial proposal to the government. This would not only reduce the target cost of an incentive type contract but would also provide additional time for implementing the improvements, presumably reducing cost over a larger number of units.

5. There are times when a contractor-proposed cost improvement may not provide the benefits originally planned. If we are to encourage creative thinking it is unfair to the contractor to have him assume all of the risks for such proposals. Perhaps such uncertainties in estimated reduced costs needs to be included by adjusting the target cost and the incentive share line to reflect such uncertainties.

CONCLUSIONS

1. A Could Cost analysis can be thought of as an opportunity for the government and the contractor, working as a team, to reexamine all facets of their current method of acquiring defense systems and products with the end objective of generating lower cost ways of obtaining a quality system or product which will meet the military need.

2. In this paper we have described the three major ways of reducing such costs:

a. properly scrubbing the requirements;
b. performing a Should Cost analysis of the contractor's work process; and
c. properly interpreting or tailoring the government directives and regulations required to acquire the desired system or product (streamlining).

There is nothing essentially new in the methodology of each of these three approaches. What is new is Dr. Costello's challenge to us to consider all of these approaches in looking for better ways of doing our job.

3. Certain obstacles are identified which prevent us from meeting the full potential for cost improvement:

a. The contractor needs incentives which will reward his efforts at cost reduction, or conversely will not reduce his revenues or profit.
b. The government needs similar incentives for their efforts.
c. Personnel with expertise in Should Cost analysis, as well as streamlining, may not be readily available to the SPO/PM office. Since such expertise is required, it must to be made available to the SPO/PM when needed.

#122

TITLE: Force Structure Development Using Correlation of Forces Methodology

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ABSTRACT:

In December, 1987, TRADOC Analysis Command-Fort Leavenworth (TRAC-FLVN) was tasked to provide supporting analysis for the 1989 Armor/Antiarmor Master Plan. The purpose of this analysis was to determine which of the systems and munitions currently being designed or developed could be eliminated without reducing the US Army's ability to accomplish its combat objectives. Sufficiency criteria, based upon correlation of forces methodology and surviving Blue force requirements, were developed to evaluate systems across functional areas. The effectiveness of individual systems was analyzed using the Europe 6.3 scenario with the Vector-In-Commander (VIC) model. Different system mixes were investigated for their ability to meet or exceed the sufficiency criteria and a series of VIC sensitivity runs was conducted to test the most cost-effective of these. This paper will discuss the development of the sufficiency criteria, their application to the evaluation of force effectiveness, and the results of the study.

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#180

TITLE: Using Theater Level Combat Simulations for Assessing Alternatives

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ABSTRACT:

All major scenarios used for planning and programming reflect US forces fighting in a coalition. Detailed analyses of the capabilities and potential improvements to the US Army's contribution in stated scenarios is a major mission of the US Army Concepts Analysis Agency (CAA). This presentation will draw on results of recent force studies at CAA using the Concepts Evaluation Model (CEM) to illustrate the relative contribution of US Army combat forces in AFCENT and the theater level impact of selected changes in US capabilities as reflected in sensitivity analyses.

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